Department of Mechanical Engineering

A STUDY OF VIBRATION SOURCES

AFFECTING MINE WORKERS

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ABSTRACT

This work describes a study conducted to evaluate (i) characteristics of vibration sources found in a mine environment and (ii) instrumentation presently available for their measurement. Results are presented for jack leg and stoper drills and for whole body vibration levels in refiner and compressor room areas. Tests were conducted at two large mine sites and sufficient data were obtained to determine characterisic rock drill vibration signatures. Comparisons are made with the recommendation of Standards concerning the development of Vibration White Finger Disease.

Laboratory tests are reported that consider approaches whereby rock drill handle vibration levels may be reduced. Existing instrumentation is tested and the task of computer interfacing a particular data recorded is reported.

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1. BACKGROUND

Prolonged exposure to high levels of vibration has been recognized for many years as a potential hazard to health. A preliminary account of the effect of vibration on workers in the mining industry and an assessment of vibration levels to which miners are exposed can be found in a recent report to CANMET carried out at the University of British Columbia by S.G. Hutton and R.L. Brubaker [1]. The major effect of vibration on workers is injury to the hand and arm. Amongst miners, operators of hand held pneumatic drills are the principal workers affected. The general term used to describe the injury to the hand and arm is Vibration White Finger Disease (VWFD).

There have been a number of studies reported on the development of VWFD amongst rock drillers and other users of pneumatic hand held tools. Countries where studies have been carried out include Norway, Sweden, Japan, Great Britain, Denmark, Italy, Poland, France and Canada. Prevelancy rates for VWFD in these studies varies from 20.9 to 91%. The prevalence rate of VWFD among miners in Canada is unknown. With the exception of reports of VWFD among uranium miners in Northern Saskatchewan in the 1960's, there has been little information available to judge the extent and severity of this problem in Canada. Reference (1) summarized the information available as of 1980.

In Canada, as in many other countries, there is presently no existing standard to regulate vibration exposure from hand held mining equipment.

There is, however, an International Standards Organization Draft Proposal entitled: "Principles for the Measurement and Evaluation

of Human Exposure to Vibration Transmitted to the Hand" (ISO DIS 5349) which is being cosidered for adoption in Canada. It is worthy of note that the vibration levels of pneumatic drills presently in use in the mining industry are such, according to this Standard, as to produce symptoms of VWFD after a relatively short exposure time.

Although the problem of whole body vibrations would appear to be less acute from an injury viewpoint, problems associated with loss of worker efficiency have been recognized. The international standard ISO 2631 "Guide for the Evaluation of Human Exposure to Whole Body Vibration" prescribes vibration limits above which decreased worker proficiency may be expected. It can be anticipated that some mine workers will be exposed to such levels.

2. PURPOSE

The purpose of this work was to study the major effects of vibration upon Canadian mine workers. To this end it was necessary to obtain quantitative data representing actual exposure conditions, to make comparisons between the results obtained and relevant standards, and to assess the applicability of existing instrumentation. The report also briefly considers how the excessive vibration levels produced by rock drills may be reduced. The work was thus divided into three distinct parts:

(i) Field Tests

The purpose of the field tests was to obtain, directly from a working environment, tests results that would characterize accurately the level of vibration that miners are exposed to. Of primary concern is the vibration of hand held rock drills. Thus the major aim of the field tests was to obtain sufficient data on vibration levels of jack leg and stoper drills to enable an accurate picture of the vibration characteristics of such drills to be formed. In this regard it was required to investigate specifically the effect of such variables as drill type, manufacturer, steel length, and air pressure; and to determine the level of accuracy with which such vibration results could be repeated. As is well recognized, rock drill vibration can cause VWFD, and a further purpose of this work was to compare the results obtained with the specifications of relevant Standards.

It was also required to obtain levels of whole body vibration that other mine workers are subjected to. Such

levels are of interest primarily in terms of reduction of worker efficiency rather than concern over health aspects.

A final purpose of the field testing was to evaluate the suitability of existing instrumentation to the needs of the Canadian mining industry.

(ii) Laboratory Tests

The purpose of this portion of the work was to investigate the possibility of reducing the vibration level of hand held rock drills using relatively simple techniques. The intent was to test the effect of vibration absorber and isolator concepts on a production rock drill with a view to developing, in the future, mechanisms for reducing vibration levels that do not require a major redesign of the drill.

During laboratory testing it was also required to evaluate the suitability of instrumentation designed specifically to measure hand arm vibration.

(iii) Computer Interfacing of Existing Instrumentation

With the widespread availability of computers and the ease with which they can process and display large amounts of data it is desirable that any data gathering system be capable of interfacing to a computer. The purpose of this part of the study was to consider how existing instrumentation could be so interfaced.

3. FIELD TESTS

3.1 Introduction

Although it has been recognized for some time that the vibration levels produced by hand operated rock drills such as those used in Canadian mining operations may be excessive, up to the present time very few vibration measurements have been conducted on such drills. Hutton and Brubaker [1] summarized the work that had been reported in the area up to 1980. The International Standards Organization revised their draft international standard ISO DIS 5349 "Guide for the measurement and assessment of human exposure to vibration transmitted to the hand" in September 1982 basing these revisions upon existing data. Representative field tests are required to evaluate the validity of the standard to Canadian drilling conditions.

The primary aim of the present field testing was to measure vibration levels of rock drills during actual drilling conditions. Such measurements are difficult to obtain. As well as the logistical problems of conducting tests in production mine environment, the instrumentation required to obtain reliable results was not designed for the rugged, wet, and dusty conditions found underground in a mine. Thus, it is not altogether surprising that there is a dearth of such experimental records. The specific aims of the field testing program were to:

(i) obtain vibration data pertaining to different types of drills commonly used by Canadian miners and to compare their respective vibration characteristics. Such data will be valuable in

considering design changes that may help reduce vibration levels;

(ii) obtain data as specified in ISO DIS 5349 that could be used to investigate the implications of the standard with respect to Canadian miners. Such data includes the exposure dose to which miners are subjected;

(iii) obtain quantative data of the effect of such operating factors as steel length, air pressure, rock type and support condition upon the vibration levels produced by rock drills;

(iv) obtain characteristic whole body vibration data for workers in refining and compressor areas.

Two large underground mines were visited:

(a) Westmin Mine, Vancouver Island, British Columbia, and

(b) Sullivan Mine, Kimberley, British Columbia.

3.2 Instrumentation and Data Processing

Measurements were conducted in the field using an accelerometer Bruel and Kjaer(B&K) 4370 or 4339), a B&K 2635 preamplifier, and a B&K 7003 tape deck. For the rock drill tests single axis readings were taken in the direction of drilling by attaching the accelerometer directly to the handle of the drill via a mechanical filter B&K UA0559 using a hose clip. On the hose clip a mount had been soldered onto which the mechanical filter was screwed. Calibration levels were recorded on the tape using a B&K 4291 accelerometer calibrator. During rock drill testing all the connections and the accelerometer were bound with tape to prevent water and dust affecting the connections. The tape deck and preamplifier were contained in a plastic bag. Despite these

measures some difficulties were still encountered. Without adequate attention to such details invalid results may easily be obtained.

The tape recorded data was subsequently analyzed by a Nicolet 660A spectrum analyzer to produce a RMS acceleration record over the interval 0-2000 Hz. This spectrum was then fed into a PDP 11-34 computer for statistical analysis, plotting and weighing according to the relevent standard. The graphical plots were produced by a Tektronix 2663 digital plotter and a Tektronix 4051 graphics terminal.

3.3 Results of Rock Drill Tests from Westmin Mine

Measurements were taken underground at the location that the miner was working that particular day. The vibration level was recorded on the tape deck for the time it took to drill a complete hole - approximately 2 minutes for each 4 ft. of penetration. On average four distinct records were recorded for each drill, although in some cases it was only possible to obtain one such record. Each different record represents either a different length of steel or a different hole being drilled. In the data quoted each different sample represents an average of 16 results taken from a different record. During such tests the drill type, number, length of steel, support conditions, air pressure and drilling time were recorded.

In order to present the large volume of results obtained in an understandable form two types of graph have been used in addition to individual spectra. In the first; the mean, maximum, and minimum values of a set of spectra have been presented and in the second the mean and standard deviations are given. These plots were obtained by calculating at each frequency point the mean, maximum, and minimum

values recorded for that set of spectra. As such therefore the plots do not themselves represent measured spectra. In accordance with ISO DIS 5349 spectra were recorded over the frequency interval 5-1500 Hz and the value of RMS acceleration has been quoted in metres/sec^2.

At the Westmin mine the jack leg drill is more commonly used than the stoper and at this mine 14 jack leg drills, 5 stopers, and 2 long toms were measured. Virtually all the drills used were made by the same manufacturer and they will be referred to as type B.

In Figures 3.1a-d are presented the spectra obtained for one jack leg (using a 6' steel) using 4 different samples (4S). These samples were obtained in this case by drilling two holes with the samples being taken from the start and end of each record. In Fig.3.1a the mean, maximum and minimum values are presented for the frequency range 5-1500 Hz, and in Fig. 3.1b for the range 5-100 Hz. Dominant peaks occur at approximately 37 Hz and 225 Hz. The peak at 37 Hz and its harmonics can be attributed to the firing action of the pneumatic drill. The peaks at 225 Hz are likely to be associated with internal resonances within the drill. From the view point of vibration white finger disease (VWFD) it should be noted that low frequency accelerations are the most significant according to ISO DIS 5349. In this standard acceleration at frequencies above 16 Hz are weighted to the extent that at 40 Hz a weighting factor of approximately .3 is applied whereas at 225 Hz the weighting factor is close to .08. As may be noted from Figure 3.1b and d the recorded peak acceleration levels varied very little during this test, i.e., they did not vary from start to end of a given hole nor did they vary between different holes.

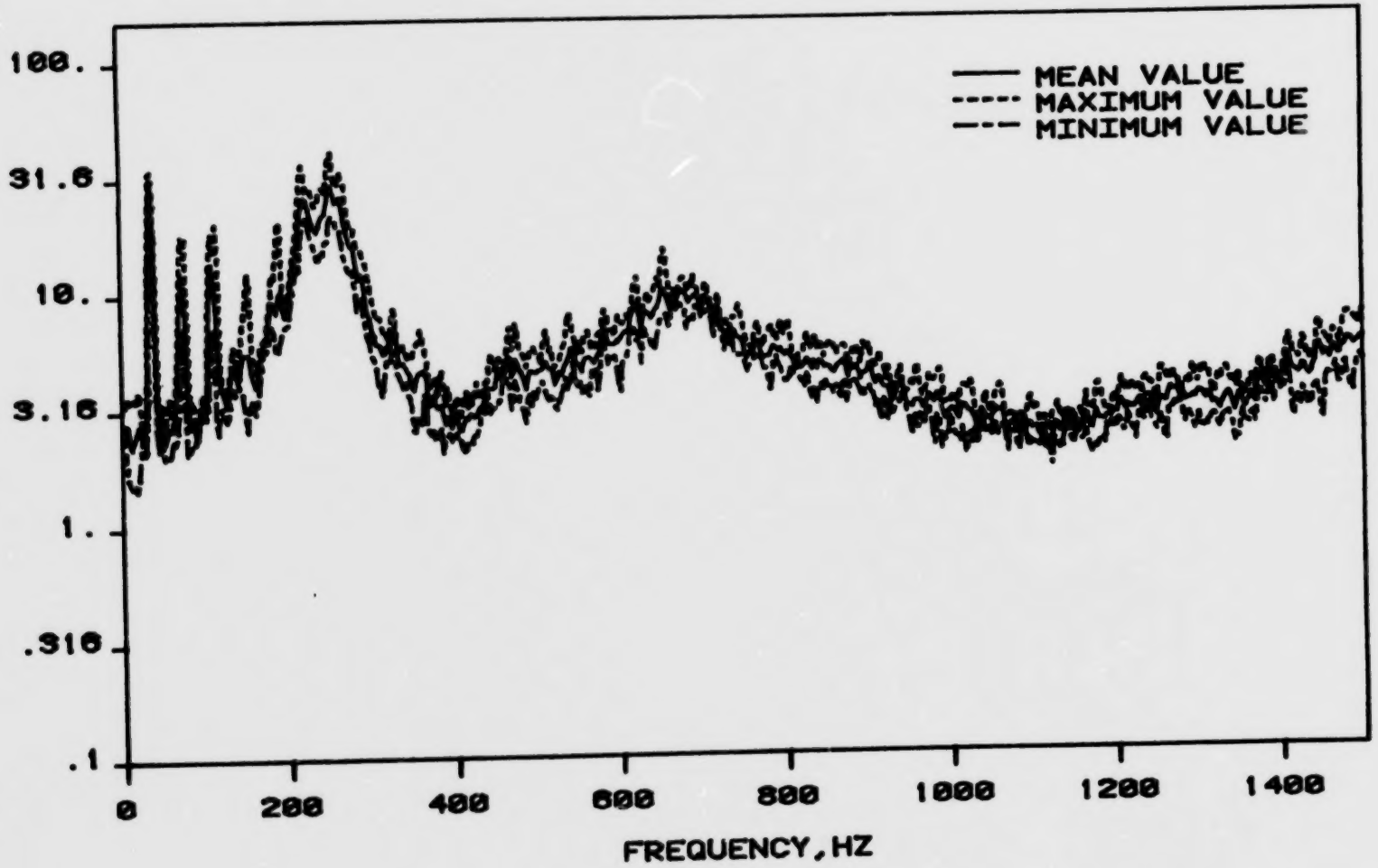


Figure 3.1a R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B, 4S)

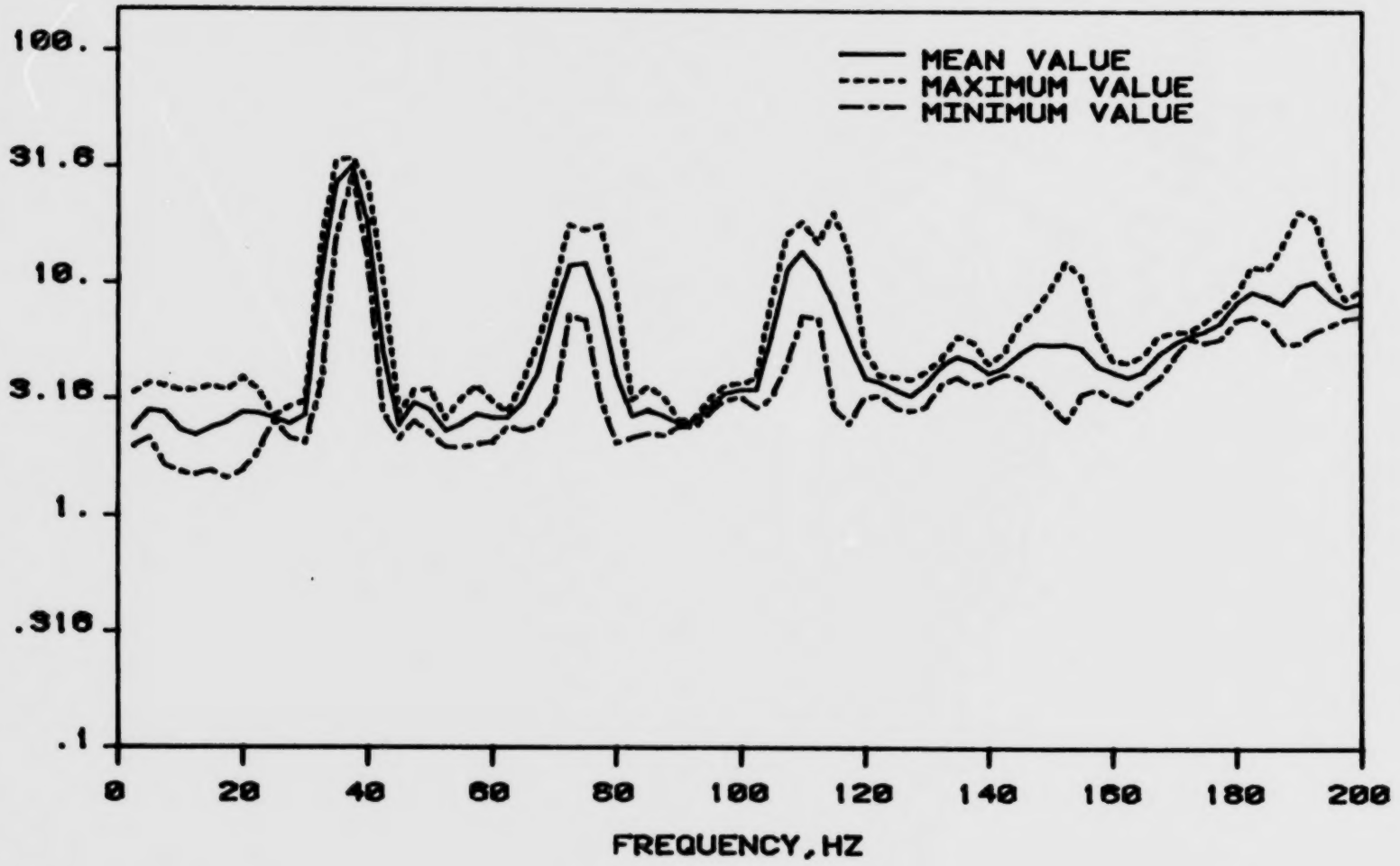


Figure 3.1b R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,4S)

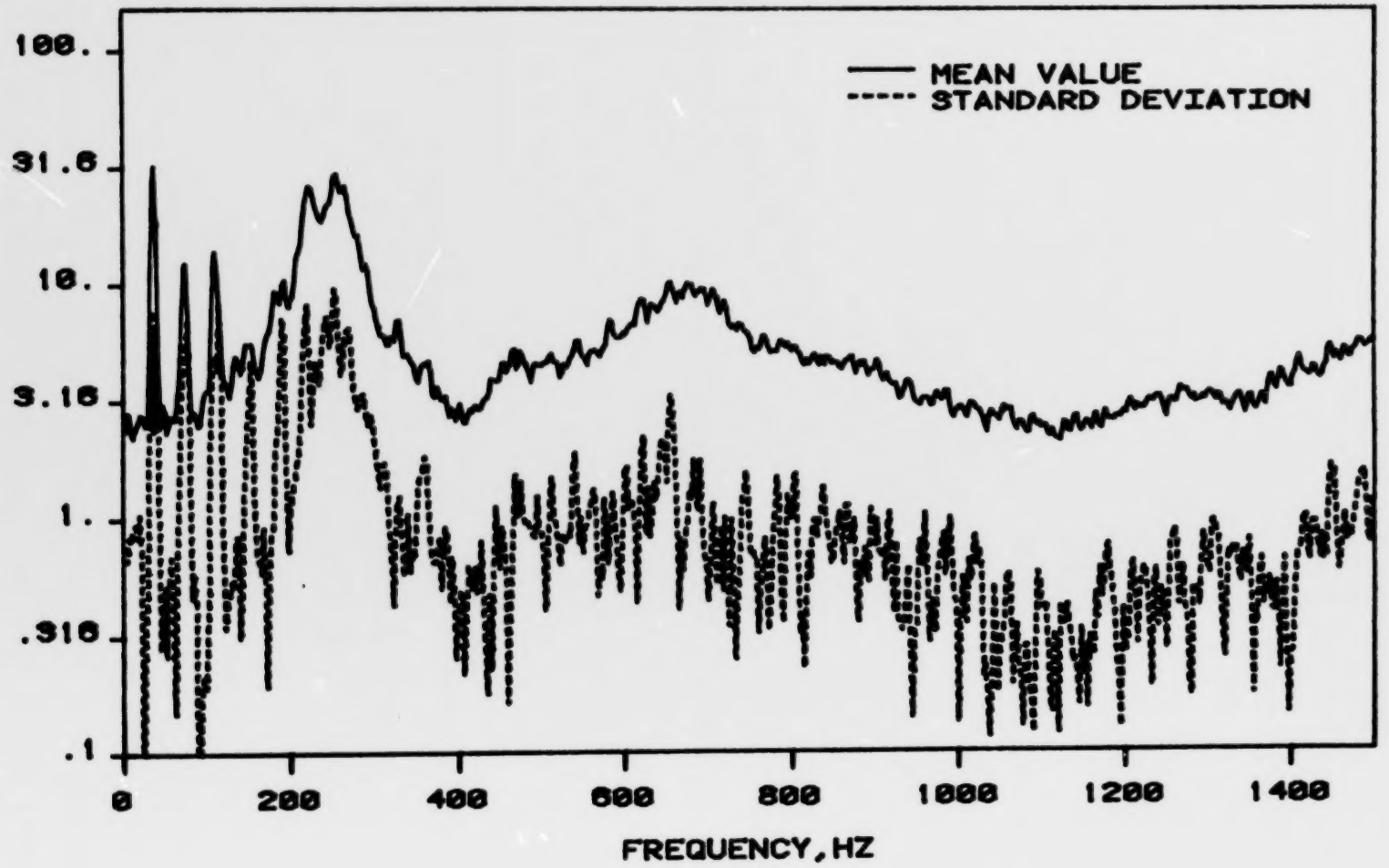


Figure 3.1c R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,4S)

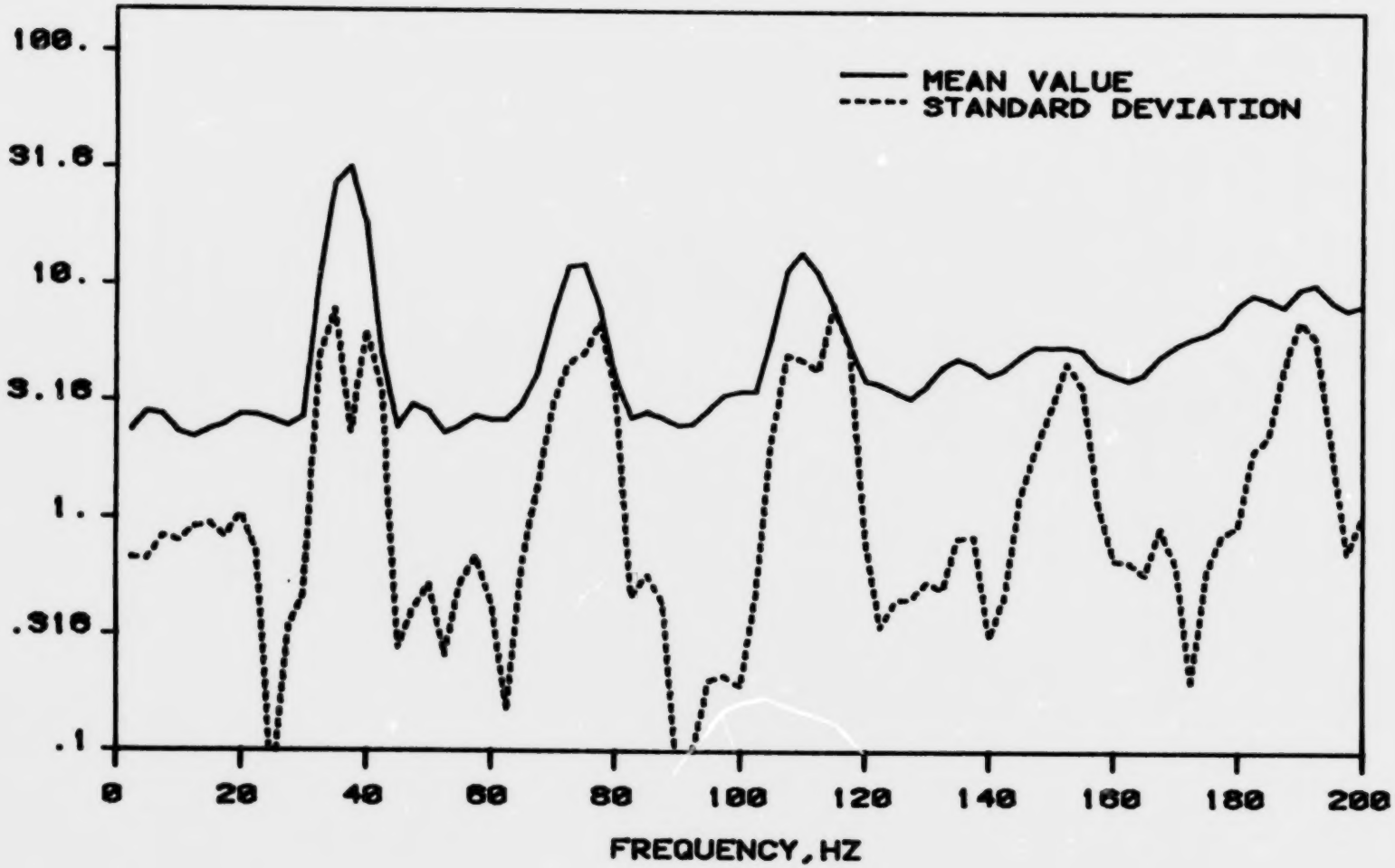


Figure 3.1d R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,4S)

In Figures 3.2 a-d are presented the results pertaining to another particular jack leg drill. These results are based upon 3 samples taken from three different records. (In all future results different samples will be obtained from different records). Again the results may be seen to be highly repeatable with, in this case, all the major harmonics of the firing frequency giving the same peak levels for different samples.

The results displayed in Figures 3.1 and 3.2 indicate that sampled data taken from any point on the vibration record is representative of the whole record. In the above cases (and for all future cases) 16 averages were obtained to compute one sample spectrum. In both cases the drill used was the same model of type B. Thus in Figure 3.2 the (B,3S) refers to the fact that drill type B was used and that the graph represents the results from 3 samples (each taken from different records).

The mean spectra displayed in Figures 3.1 and 3.2 may be seen to have almost the same shape. In Figures 3.3 are presented the results of measurements conducted on 14 jack leg drills of type B. These results were obtained at different locations, using different steel lengths and drilling into different rock conditions. However, as may be noted the mean spectrum follows very closely those presented in Figures 3.1 and 3.2. This indicates that the drill has a well defined vibration spectra that is typical of that drill. Such a spectrum may be referred to as the vibration signature of the drill as it possesses an identifying characteristic for the drill. This result indicates that the drill signature is essentially independent of the operating variables that were involved in the tests

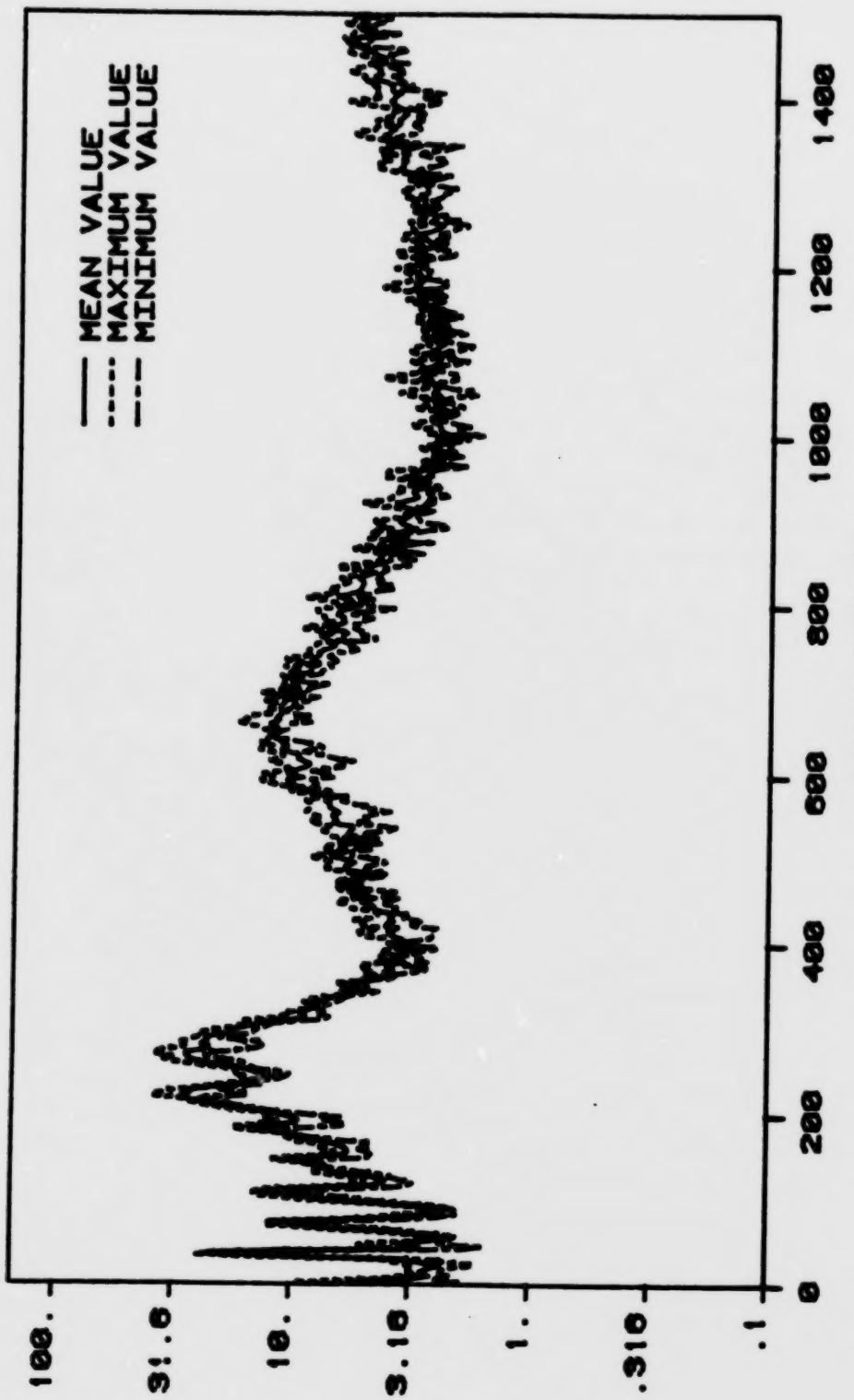


Figure 3.2a R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

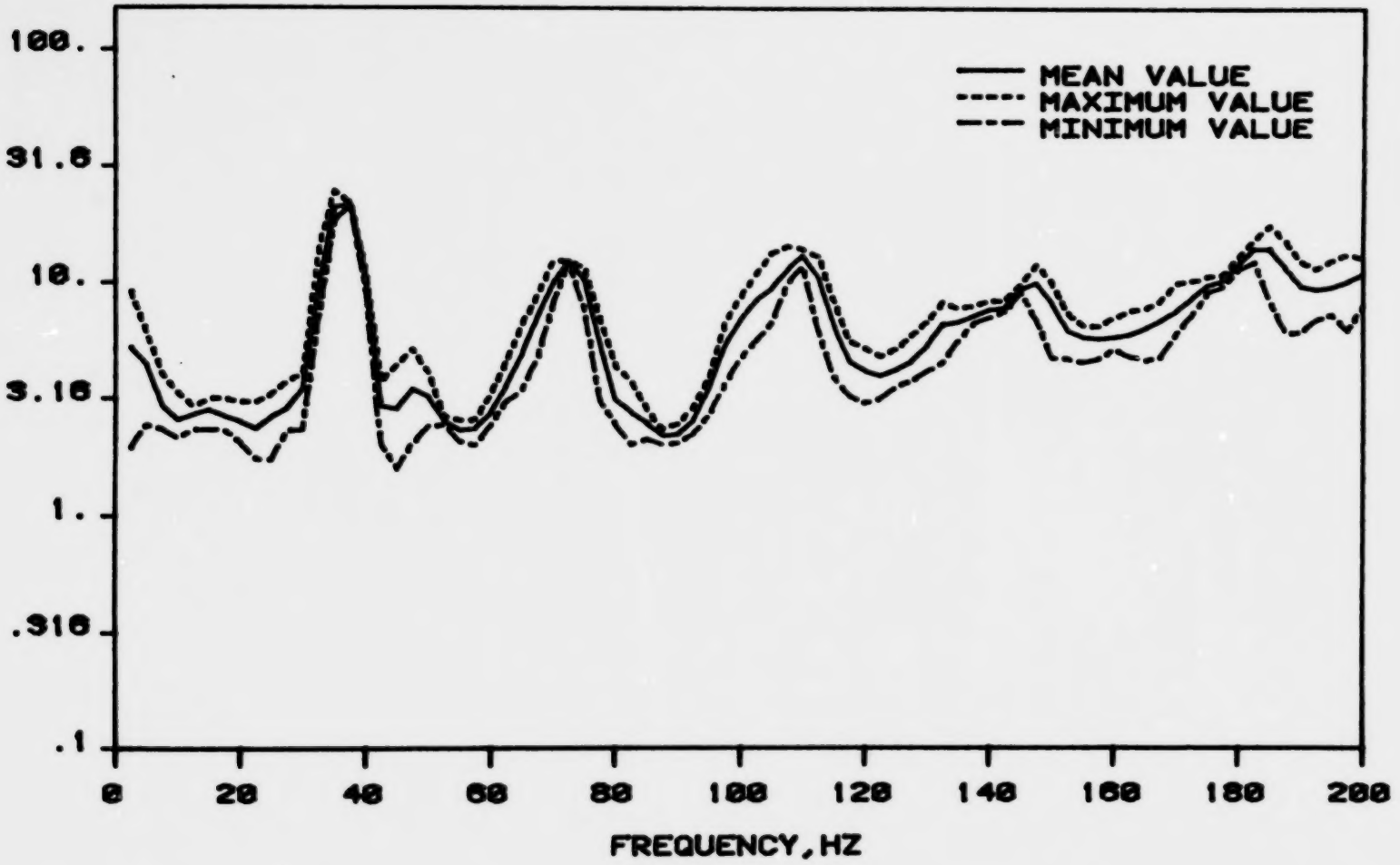


Figure 3.2b R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

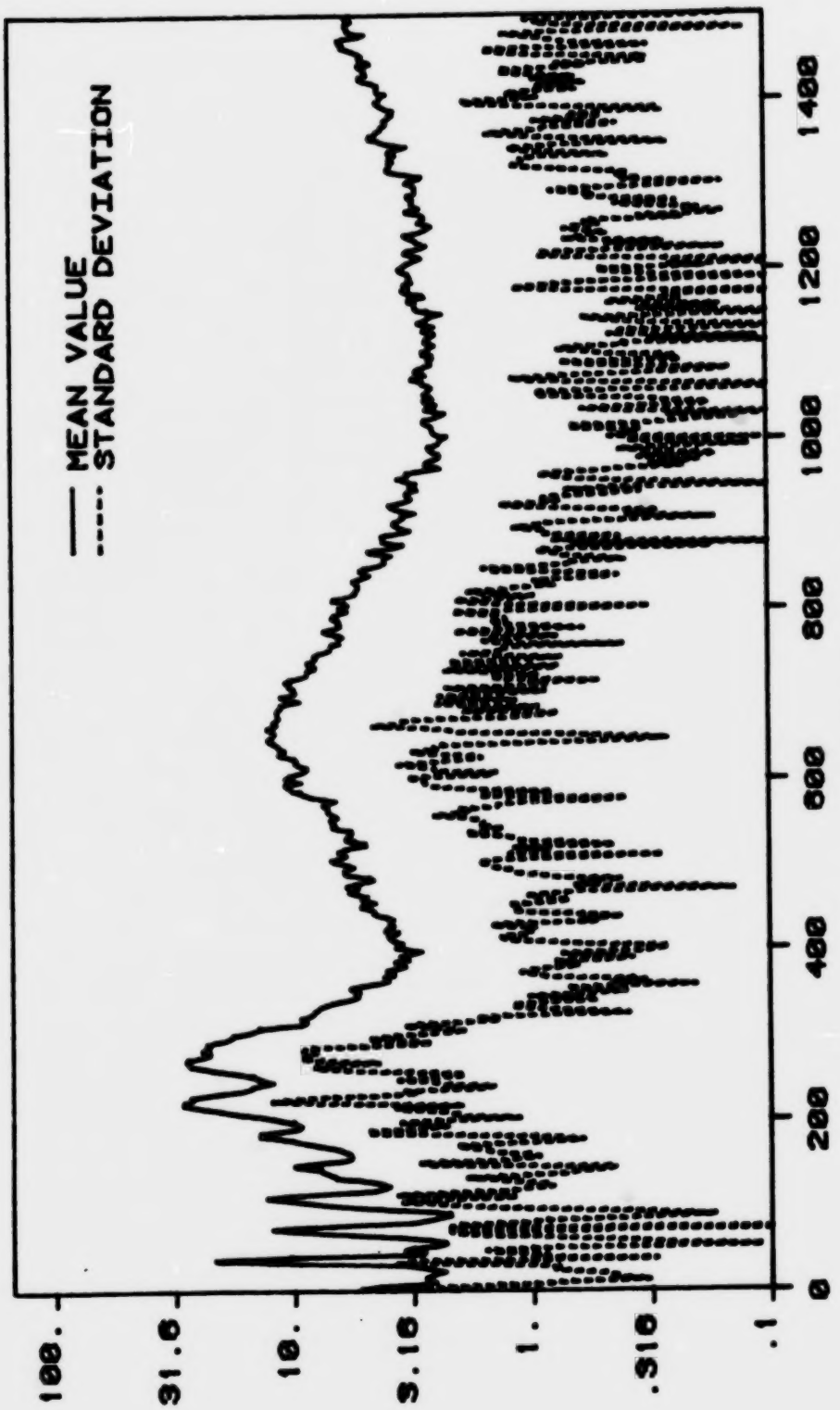


Figure 3.2c R.M.S. SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

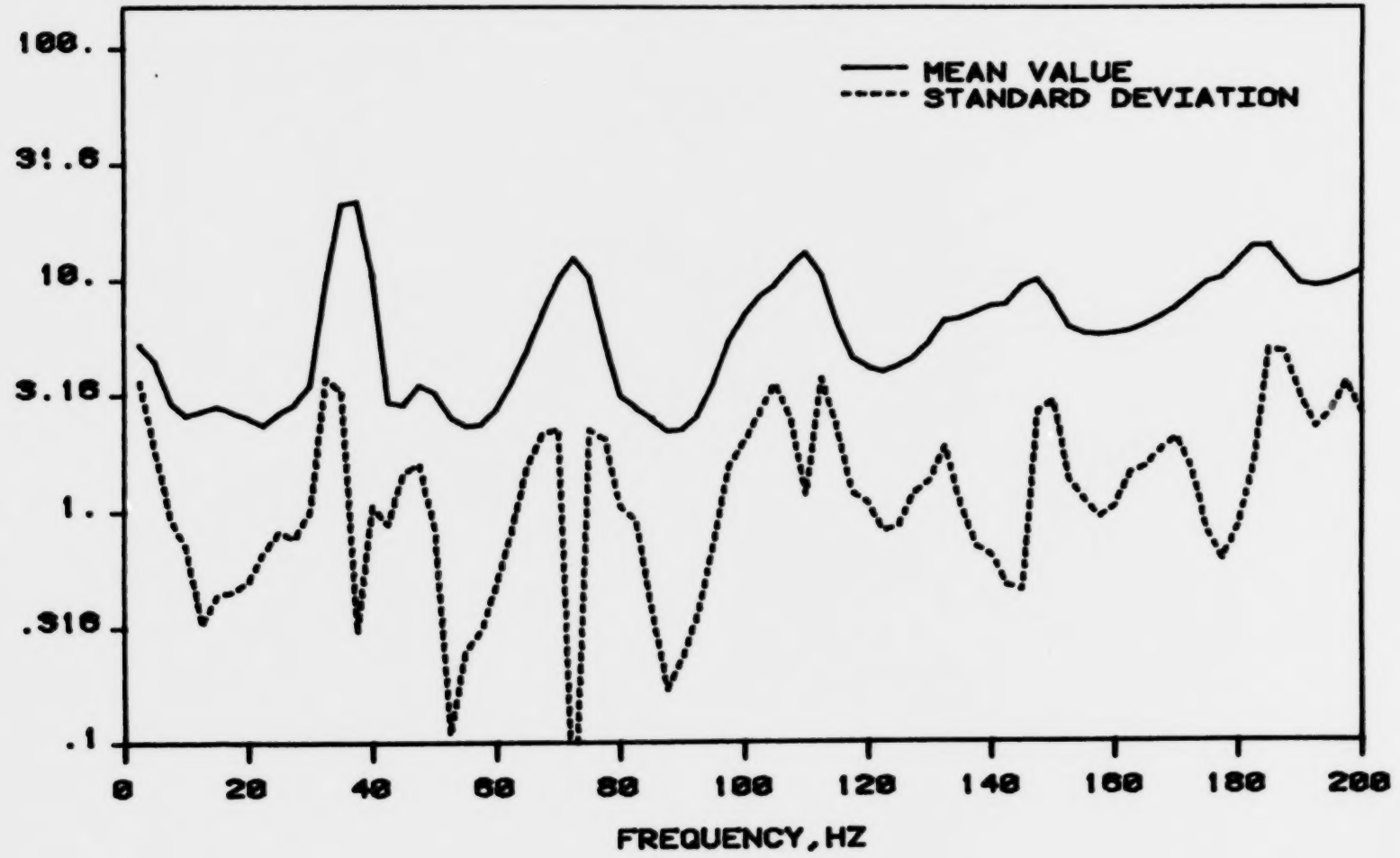


Figure 3.2d R.M.S. SPECTRA FOR SINGLE JACK LEG DRILL (B,3S)

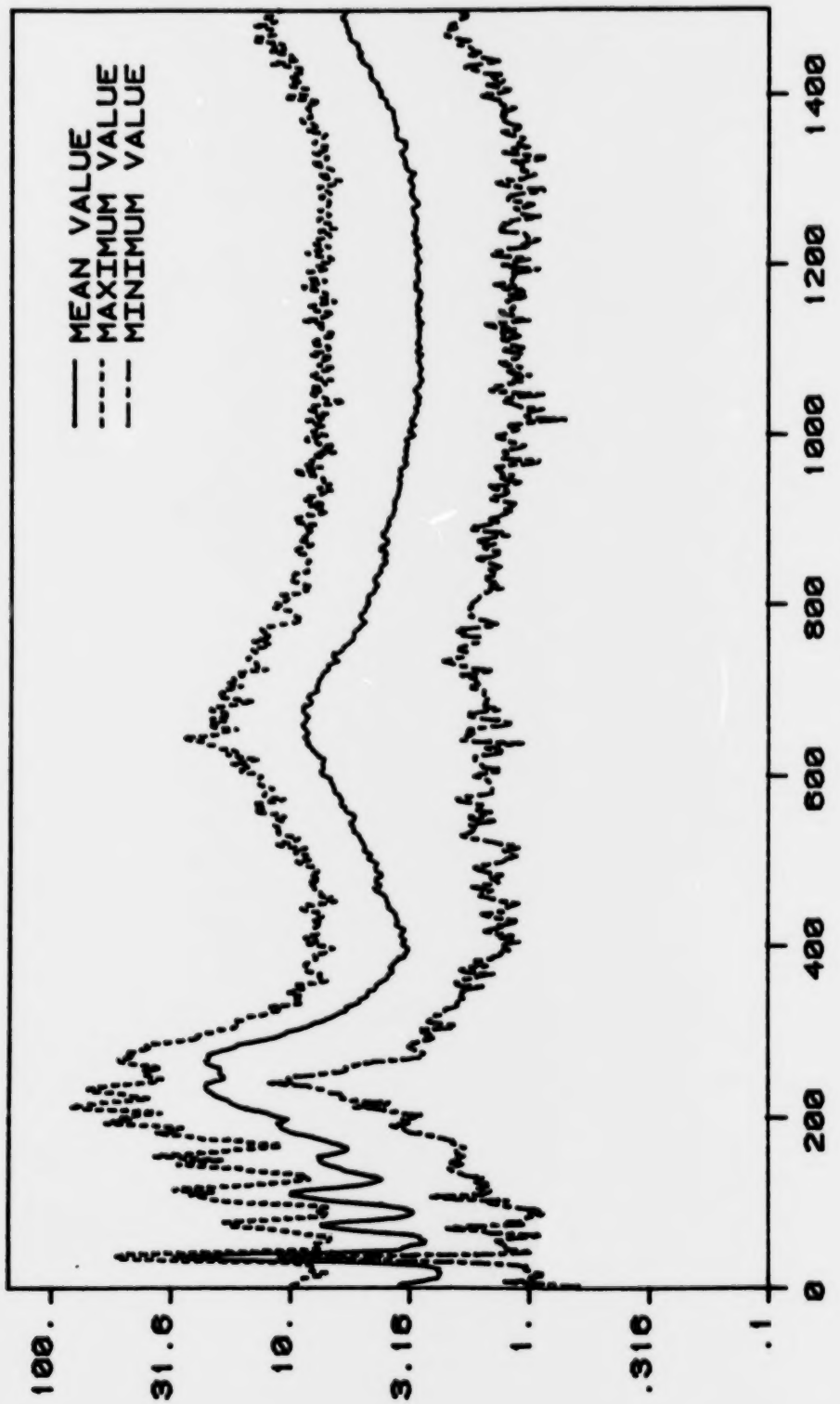


Figure 3.3a R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

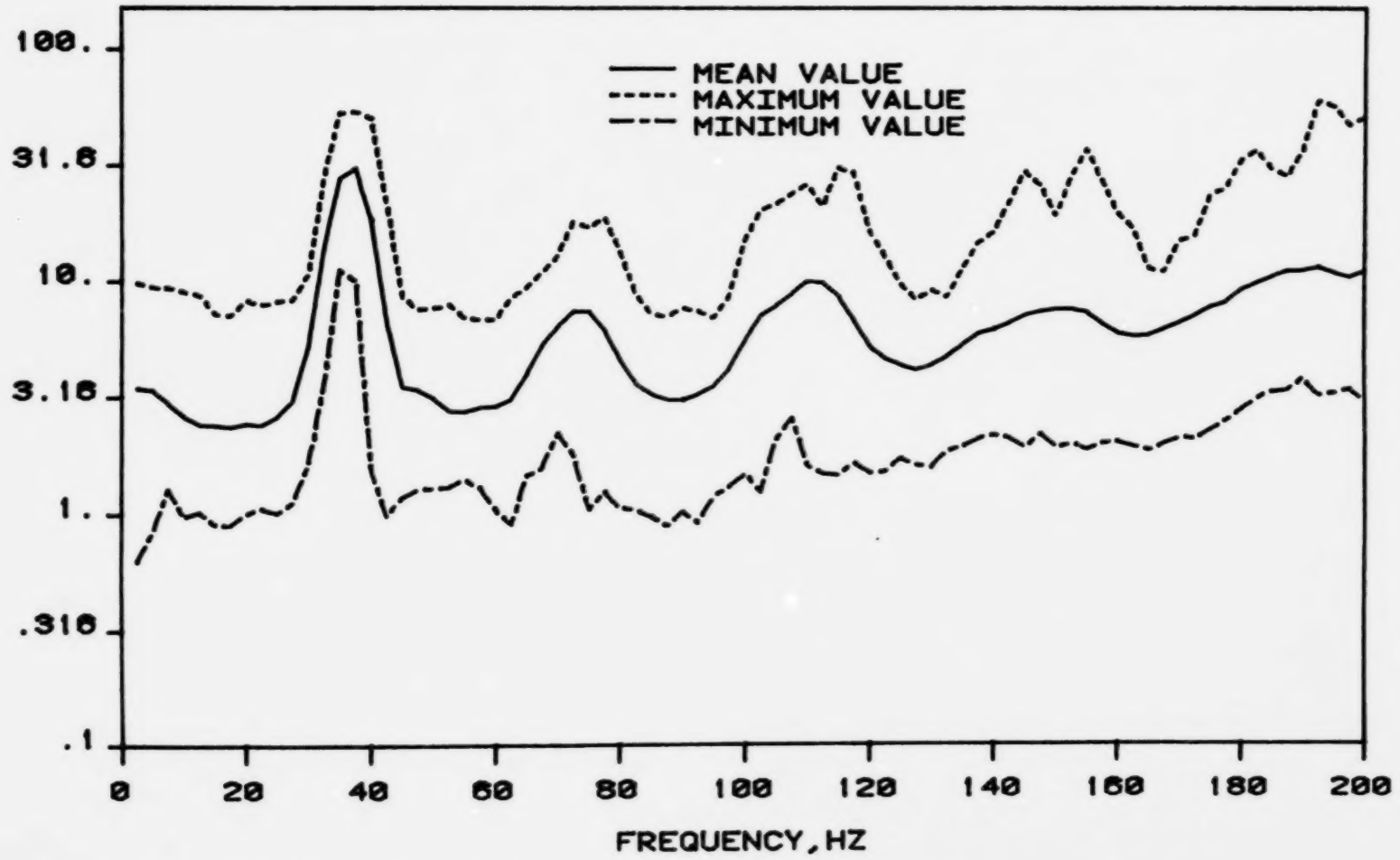


Figure 3.3b R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

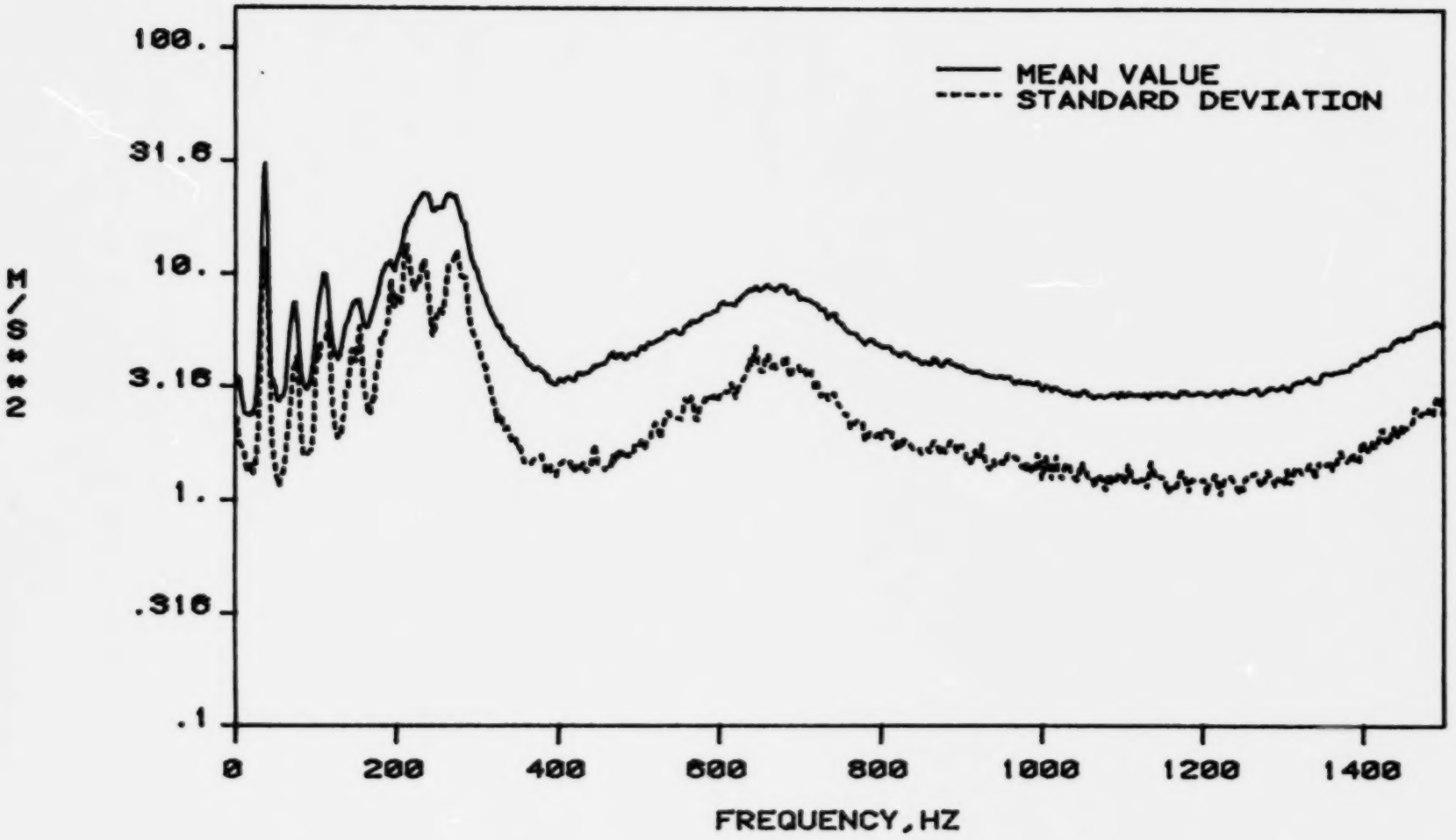


Figure 3.3c R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

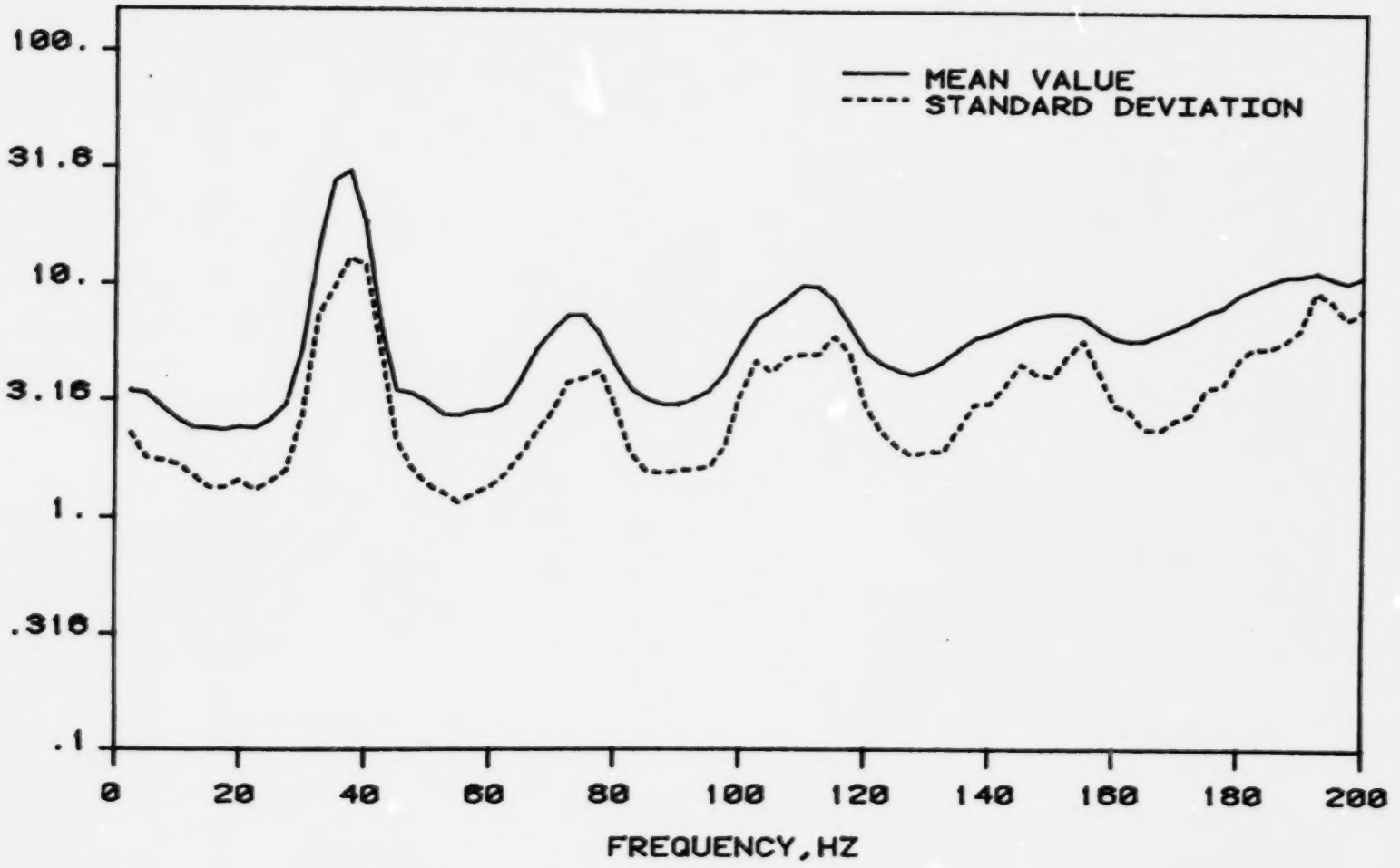


Figure 3.3d R.M.S. ACCELERATION SPECTRA FOR 14 JACK LEG DRILLS (B,39S)

conducted. As would be expected the variation involved between the vibration levels at any given frequency is much larger than for a test on a single drill. Accelerator levels at the firing frequency have a maximum value in excess of 50 m/s^2 with a mean value of 30 m/s^2.

Plotted in Figures 3.4a-d are the results obtained from a single jack leg of a different type (D). The vibration signature of this drill is somewhat different to that obtained for drill type B. A dominant peak at the firing frequency remains (at approximately the same level as for drill type B) but the spectrum shape above 200 Hz is quite different.

In order to investigate any possible effect of steel length on vibration levels, records were taken on 6 jack legs drilling with 4' steel (Figure 3.5) and for the same 6 drills drilling with 8' steel (Figure 3.6). A comparison of the mean levels obtained is presented in Figures 3.7a and b. The results do not indicate any significant dependence on steel length. Also, as none of the other results collected indicated any correlation between steel length and vibration level it was concluded that its effect could be neglected in terms of assessing vibration effects according to ISO DIS 5349.

In Figure 3.8 the results of tests conducted on 2 long tom drills of type B using 6 samples (B,2D,6S) are presented. The mean spectrum has the same general pattern as for the jack leg drill but with a lower peak at the firing frequency, and a significantly larger peak at 200 Hz.

In Figure 3.9 the results for a single stoper drill of type B; and in Figures 3.10 a-d the results of 38 samples taken from 5 stoper

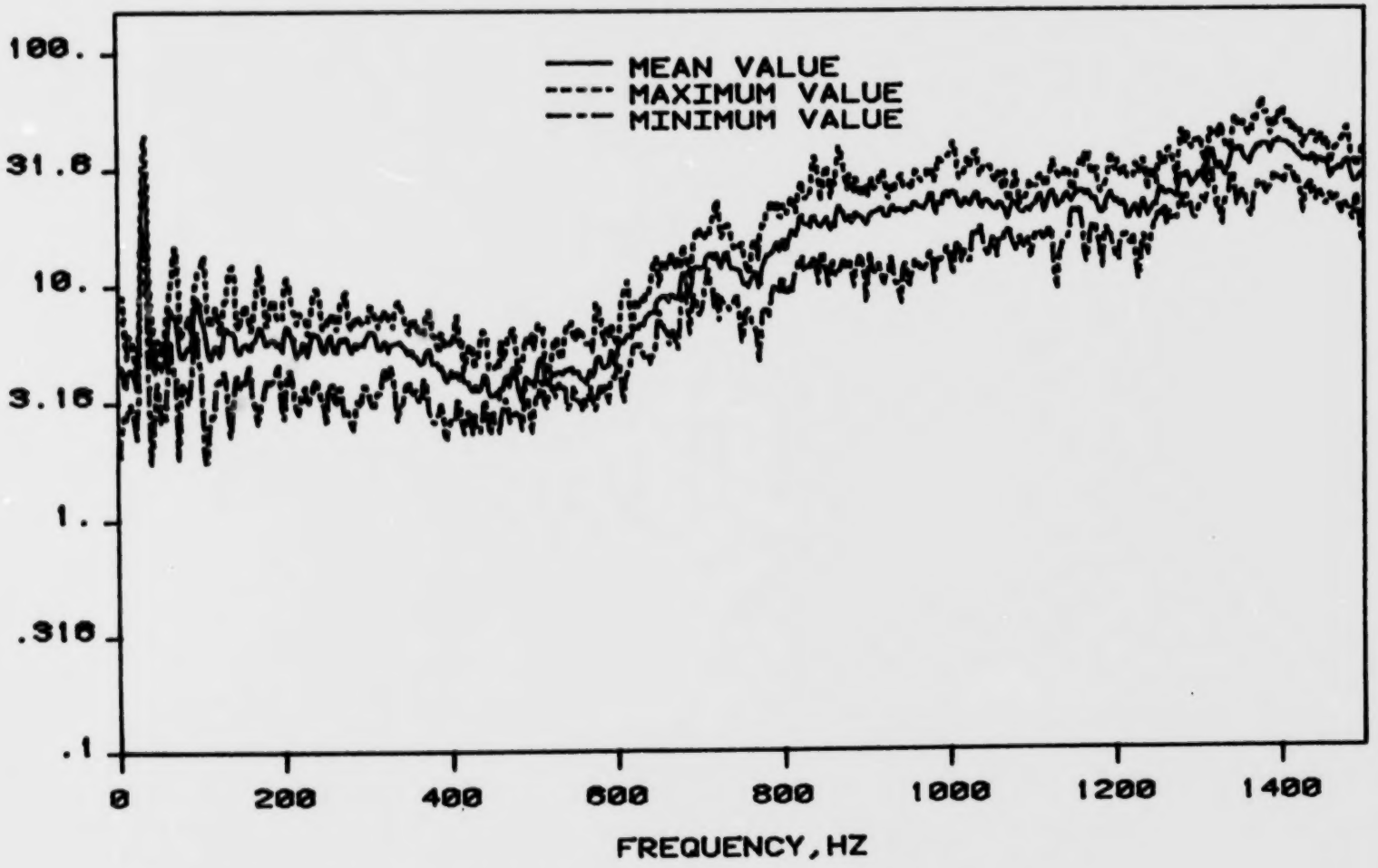


Figure 3.4a R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

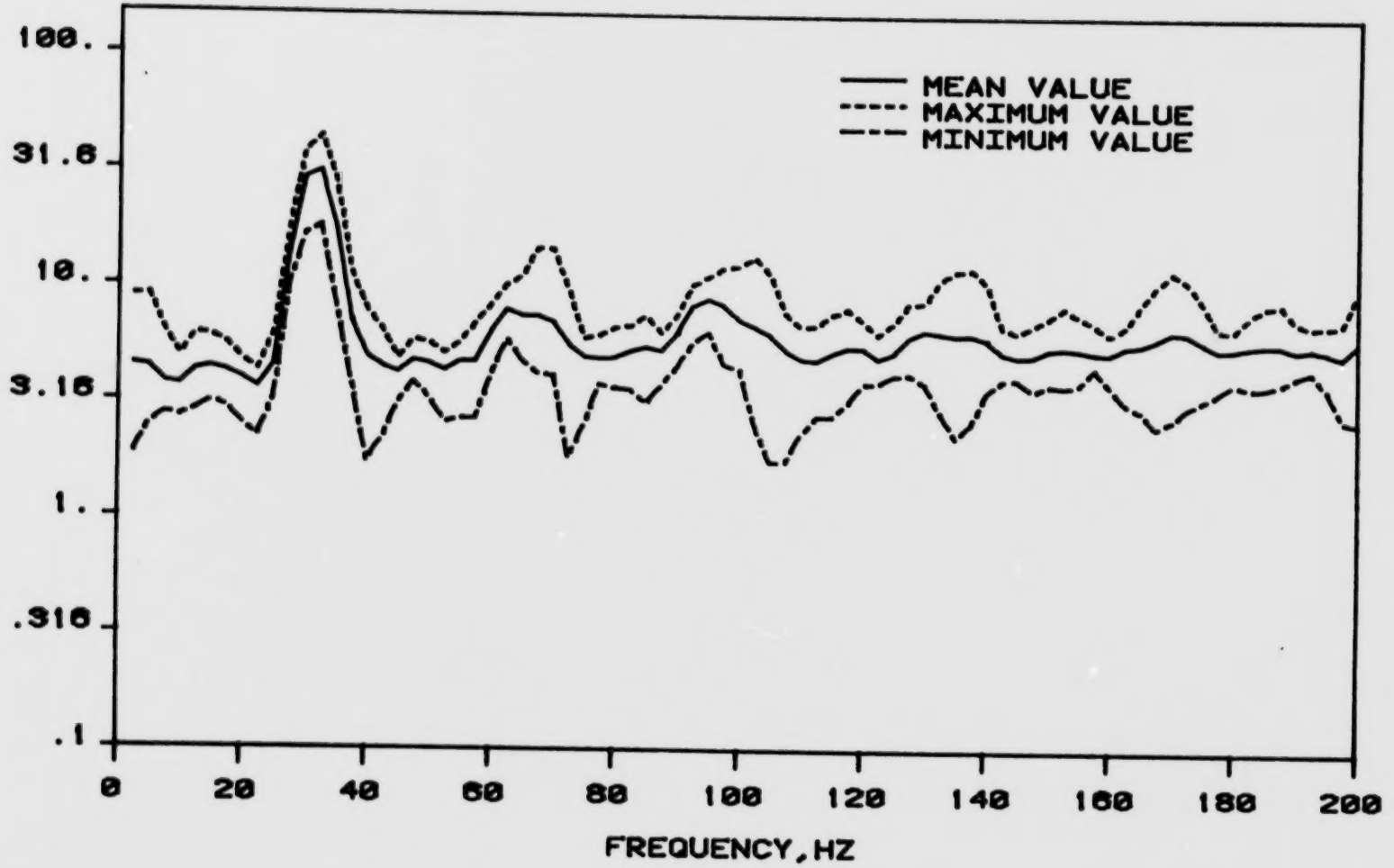


Figure 3.4b R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

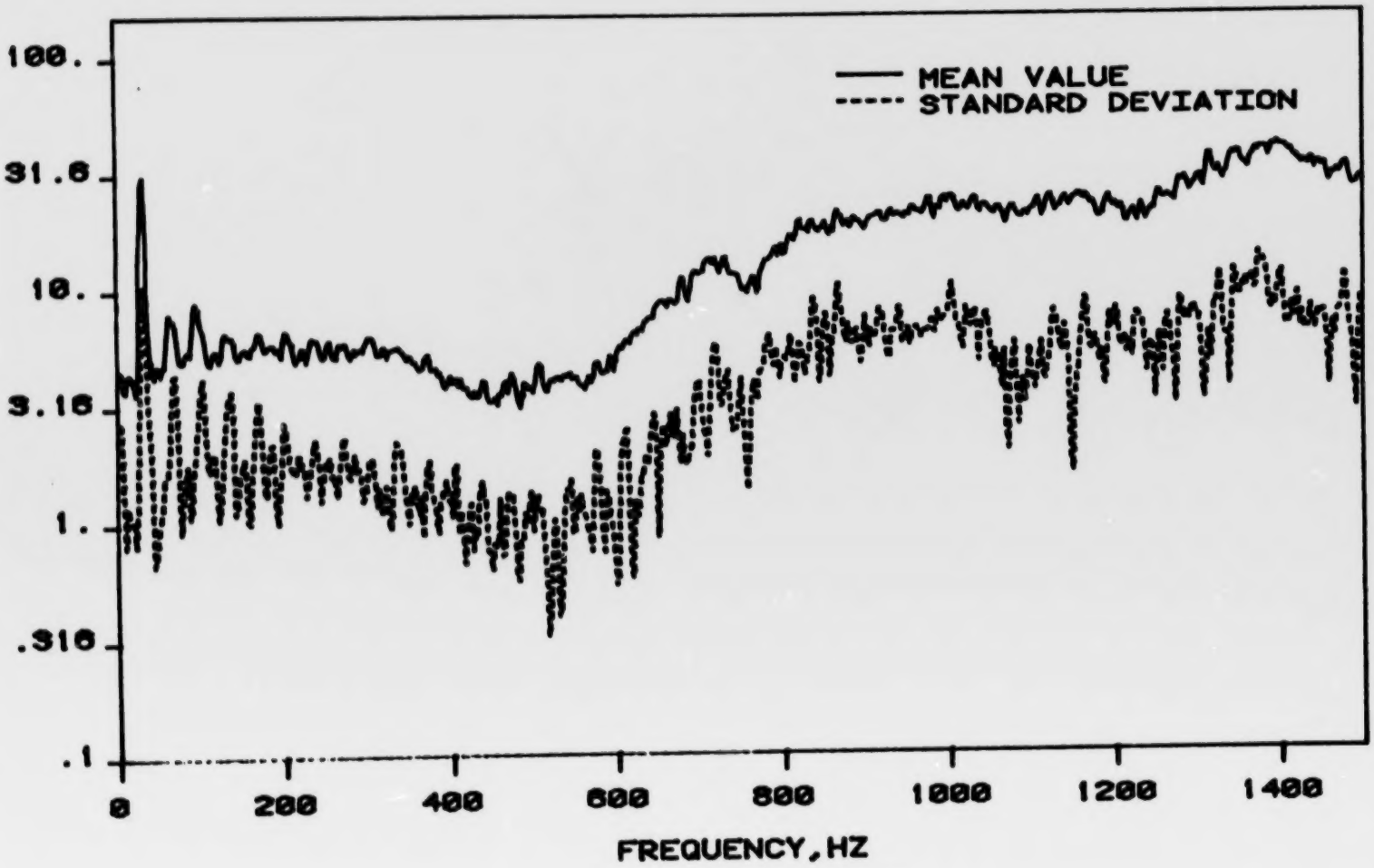


Figure 3.4c R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

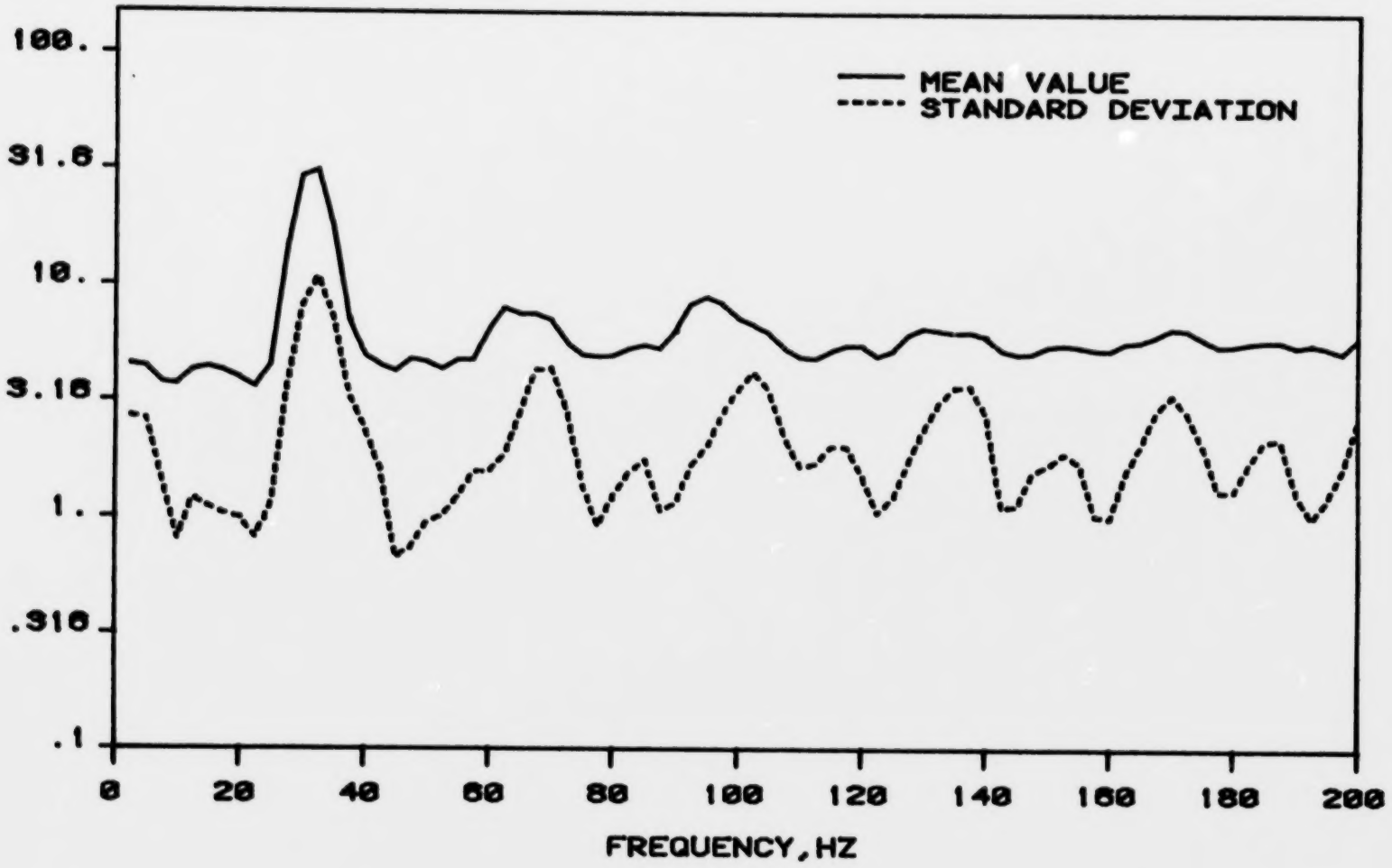


Figure 3.4d R.M.S. ACCELERATION SPECTRA FOR SINGLE JACK LEG DRILL (D,5S)

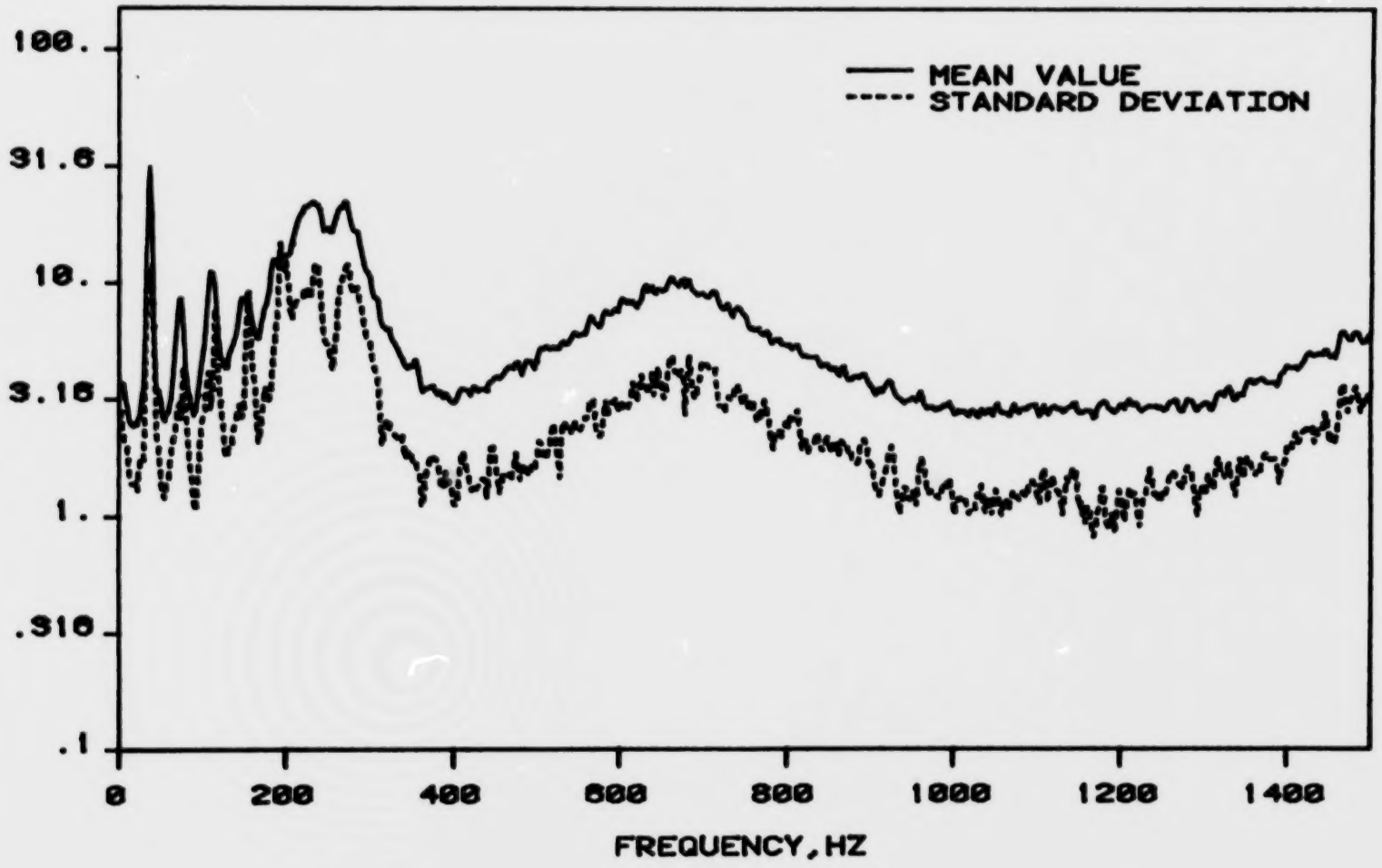


Figure 3.5 R.M.S. ACCELERATION SPECTRA FOR 6 JACK LEG DRILLS USING 4' STEEL (B,12S)

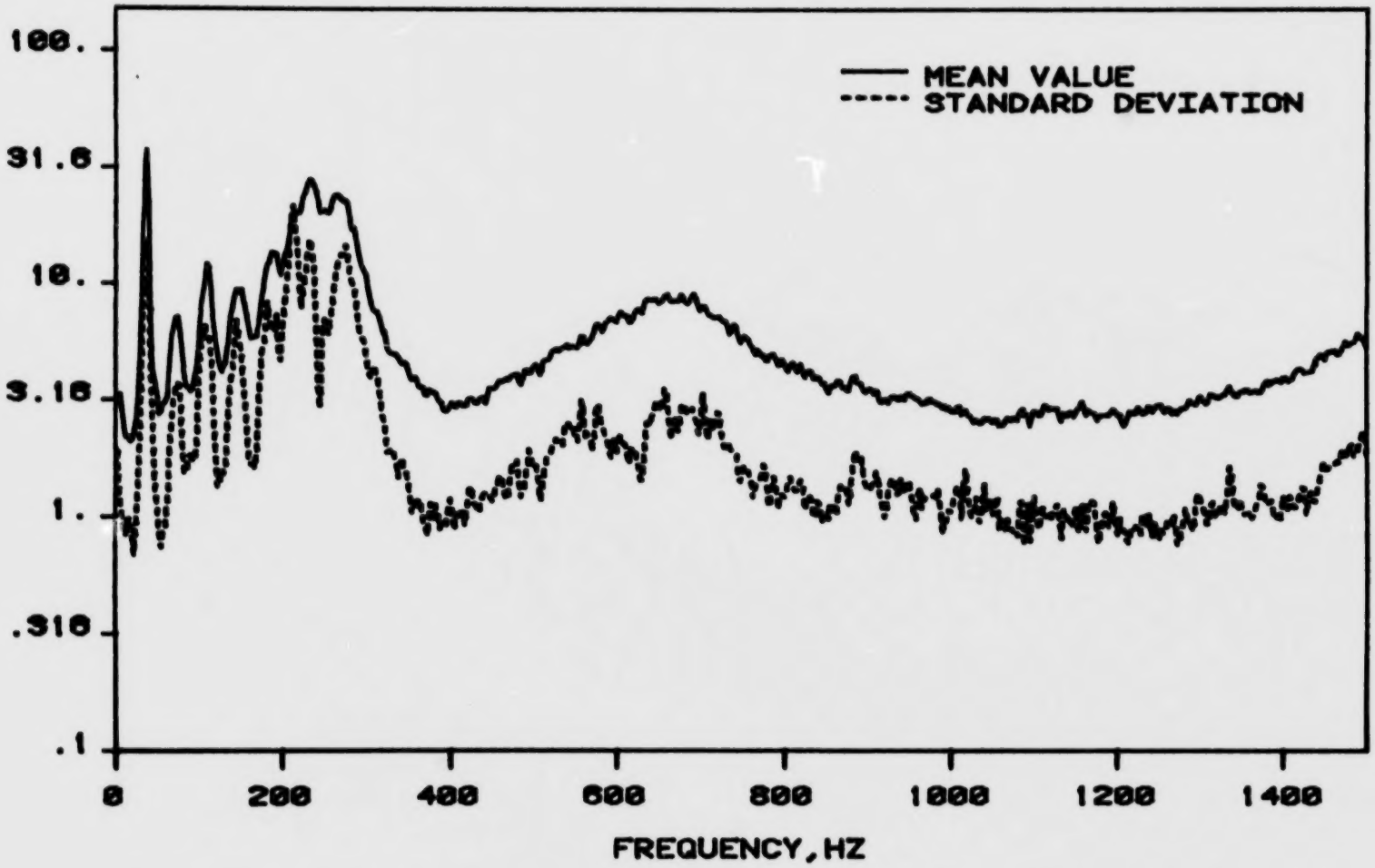


Figure 3.6 R.M.S. ACCELERATION SPECTRA FOR 6 JACK LEG DRILLS USING 8' STEEL (B,12S)

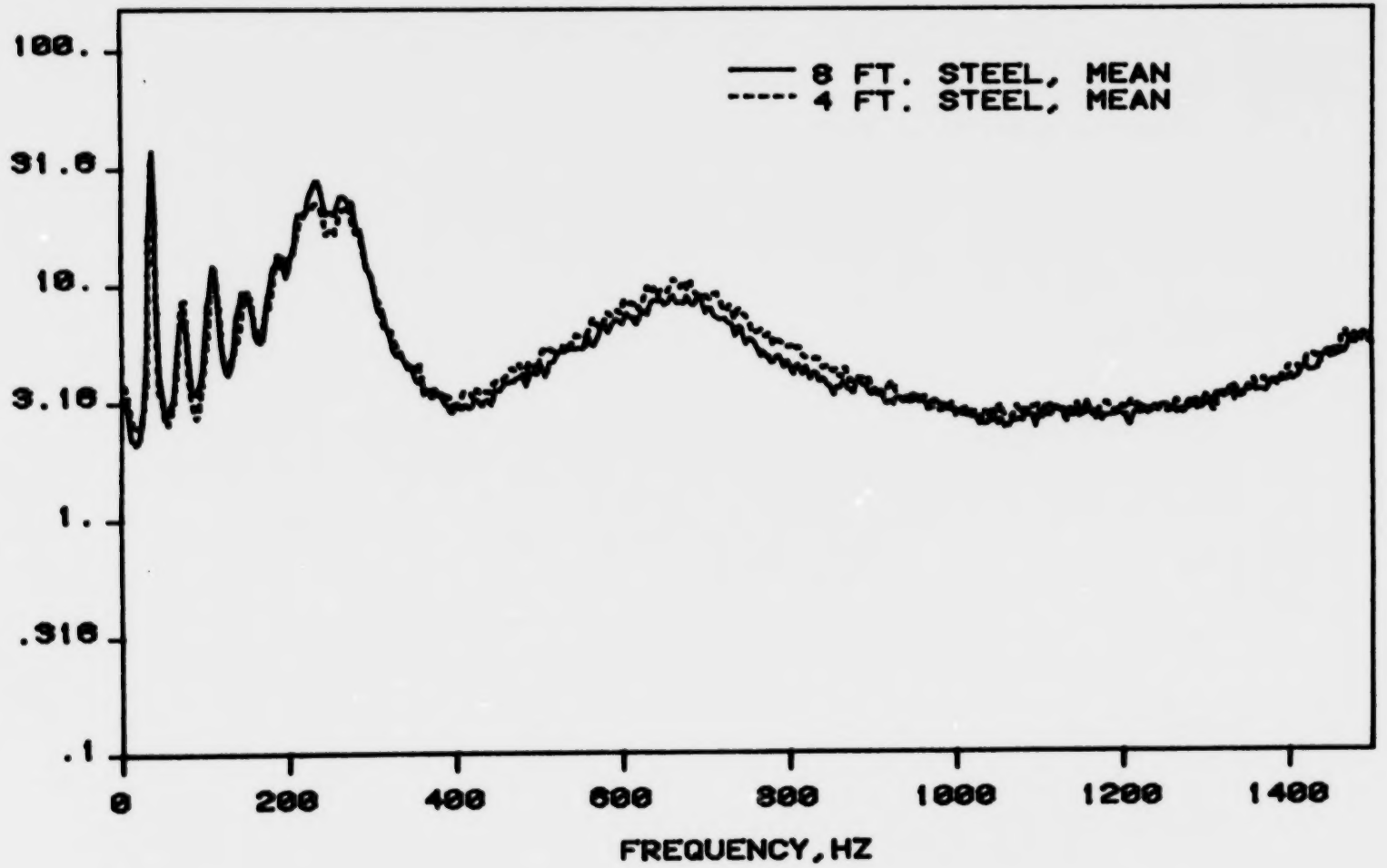


Figure 3.7a COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR JACK LEG DRILLS USING DIFFERENT STEEL LENGTHS (B,6D,12S)

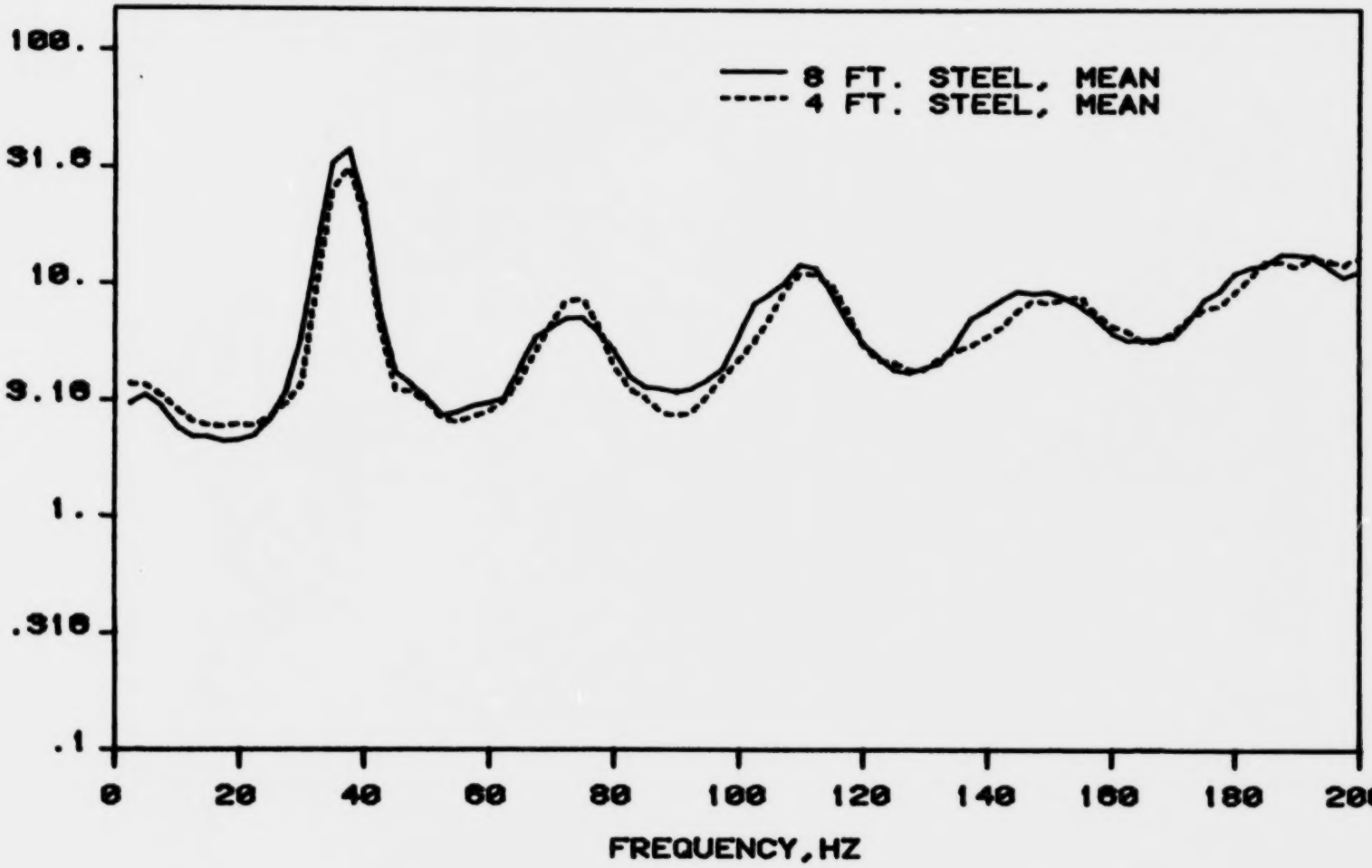


Figure 3.7b COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR JACK LEG DRILLS USING DIFFERENT STEEL LENGTHS (B,6D,12S)

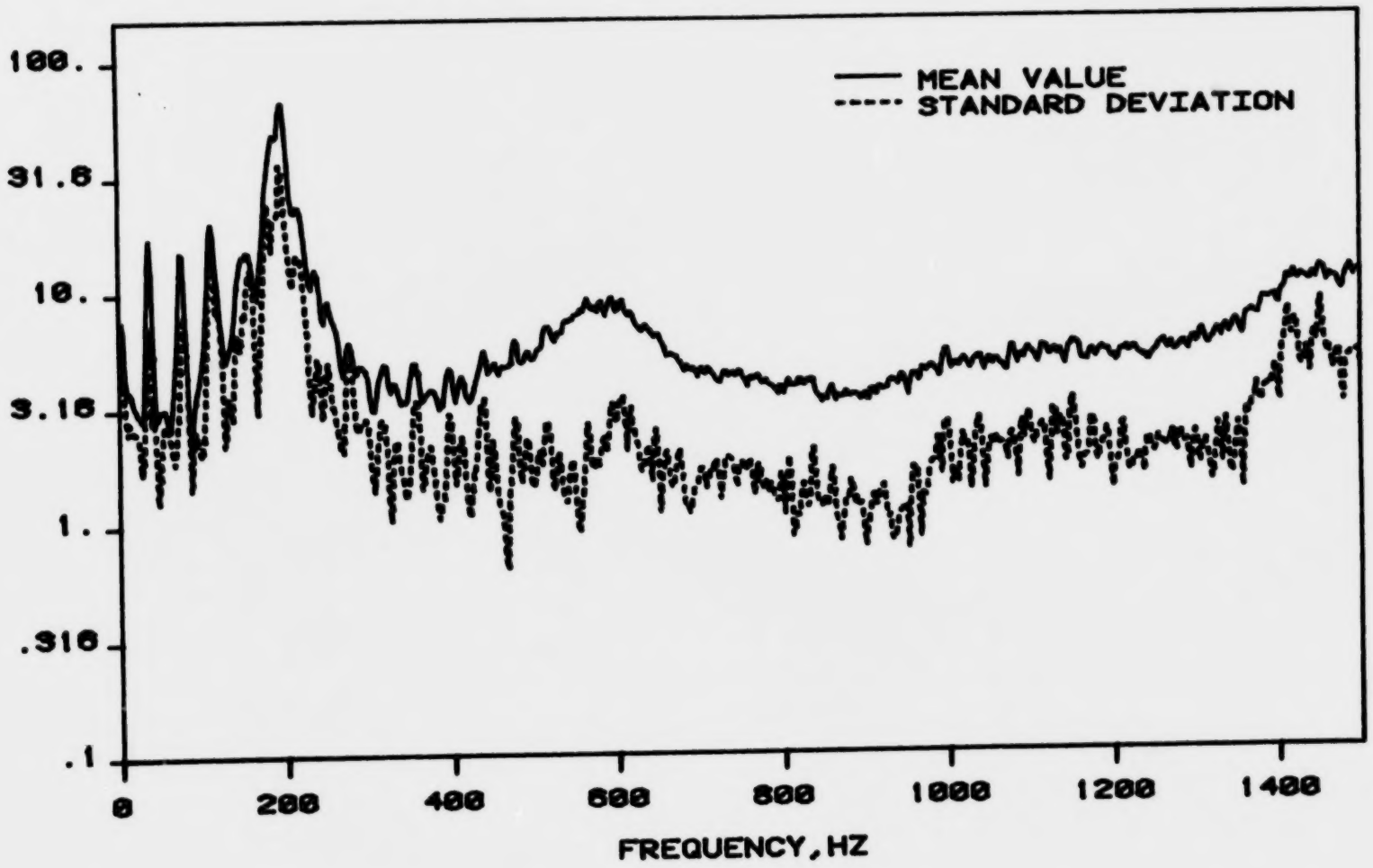


Figure 3.8 R.M.S. ACCELERATION SPECTRA FOR LONG TOM DRILLS (B,2D,7S)

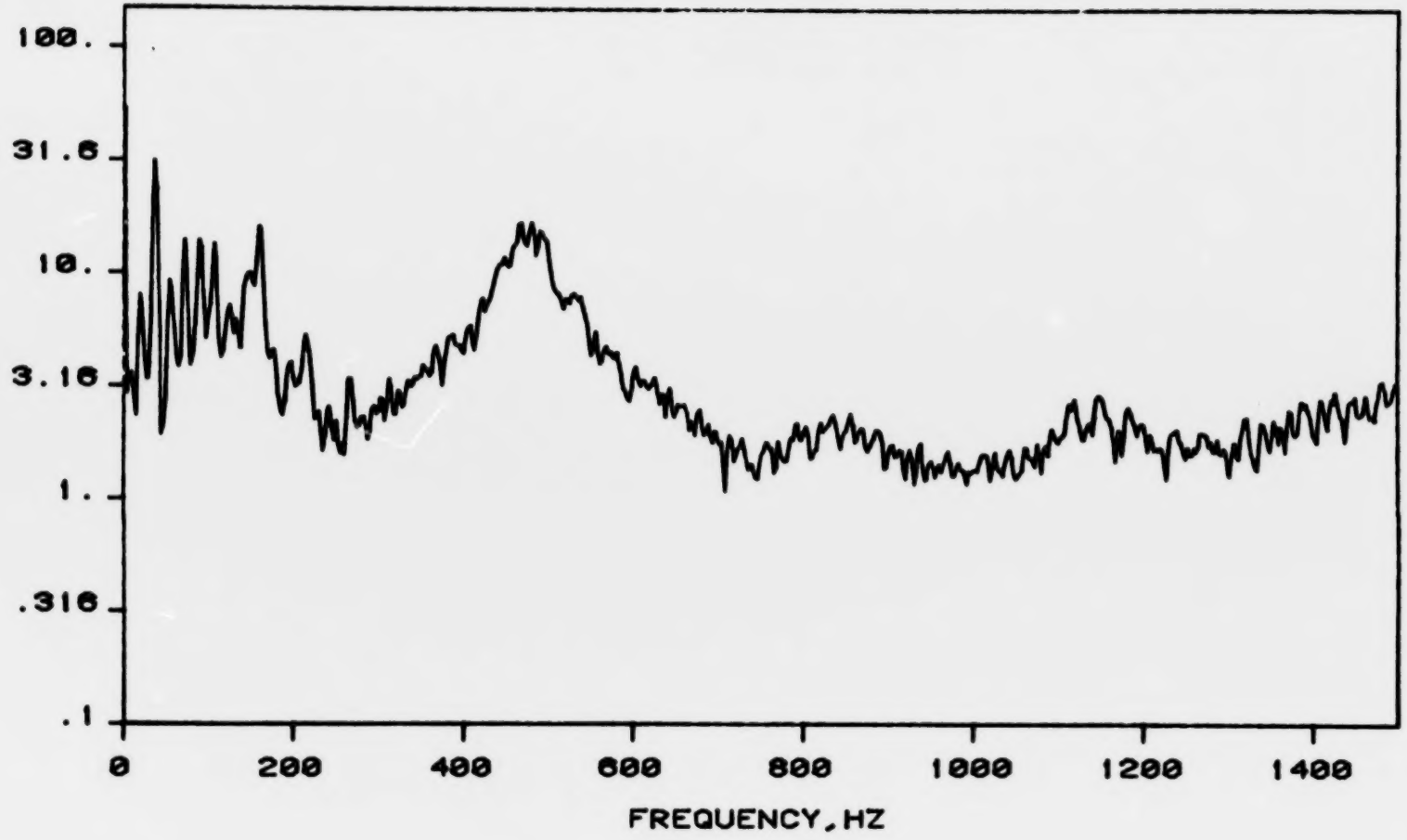


Figure 3.9 R.M.S. ACCELERATION FOR SINGLE STOPER (B,1S)

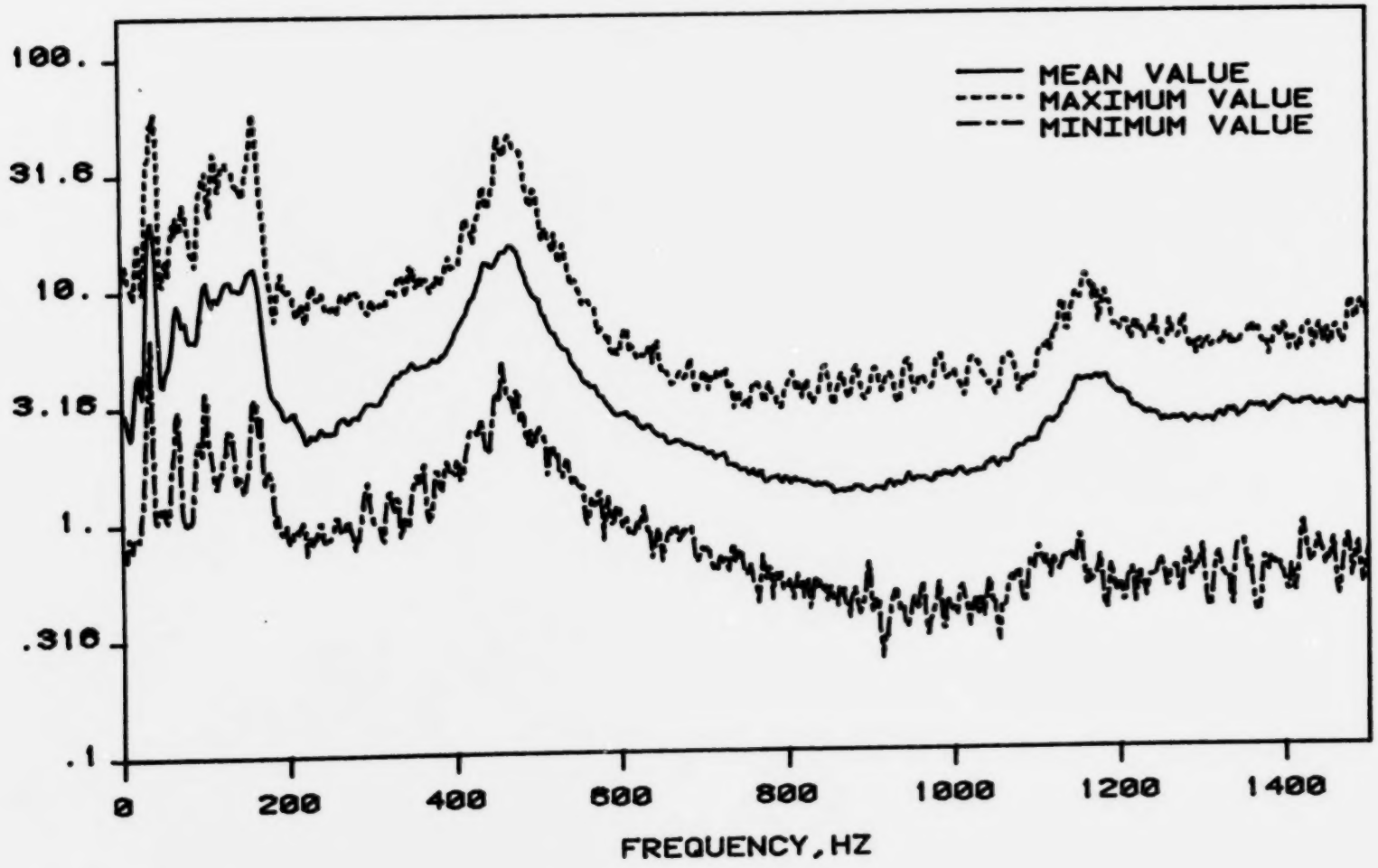


Figure 3.10a R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

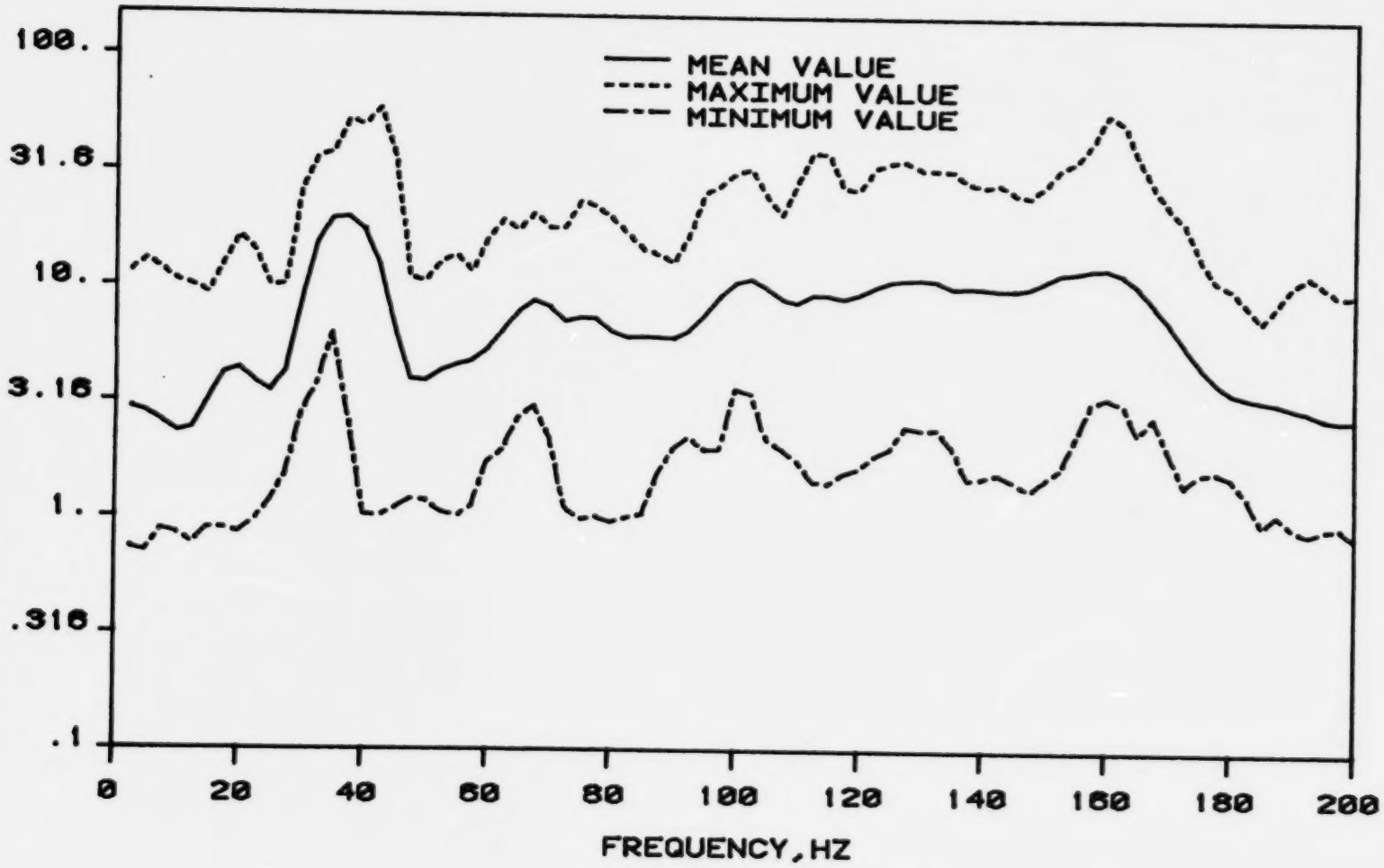


Figure 3.10b R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

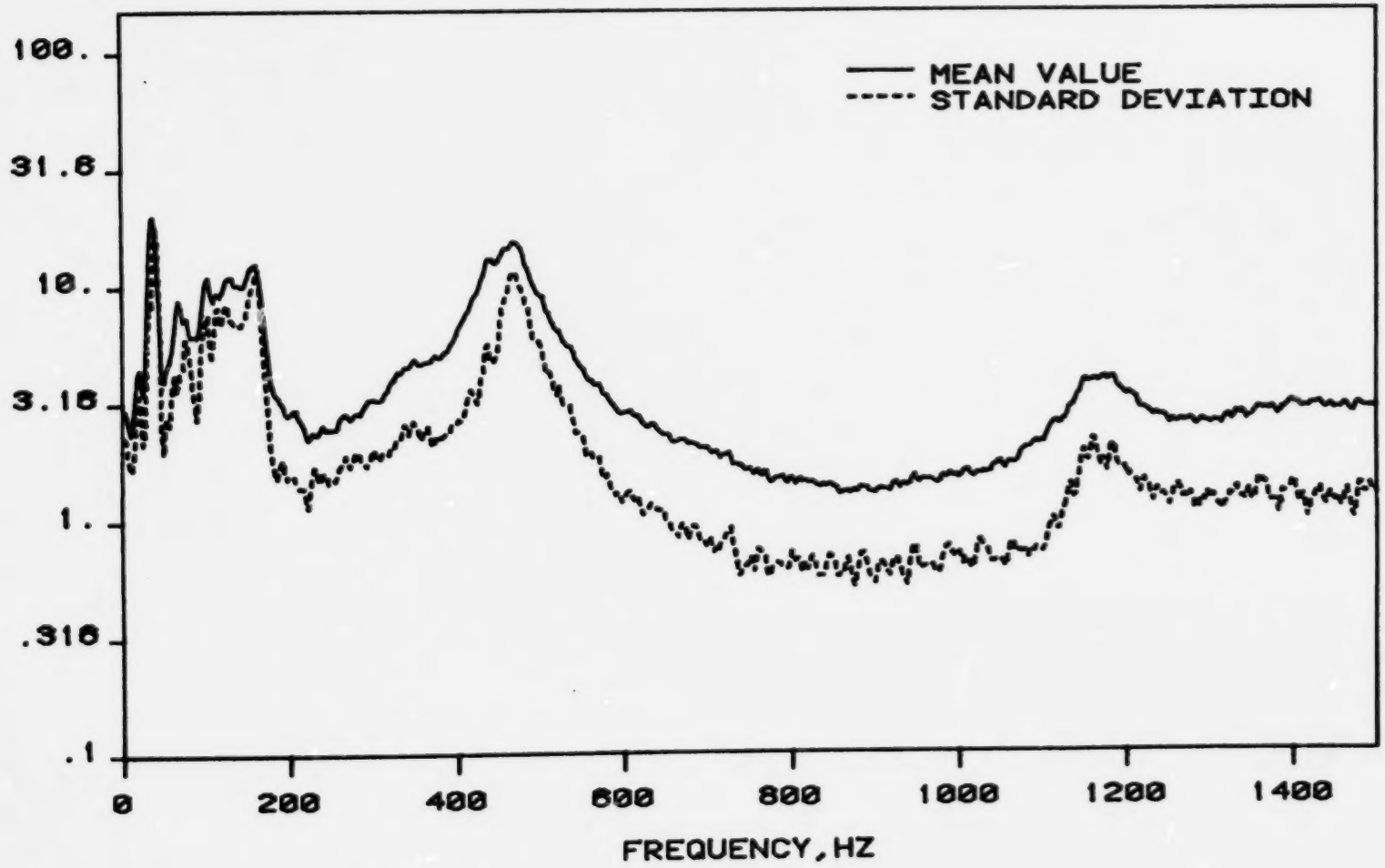


Figure 3.10c R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

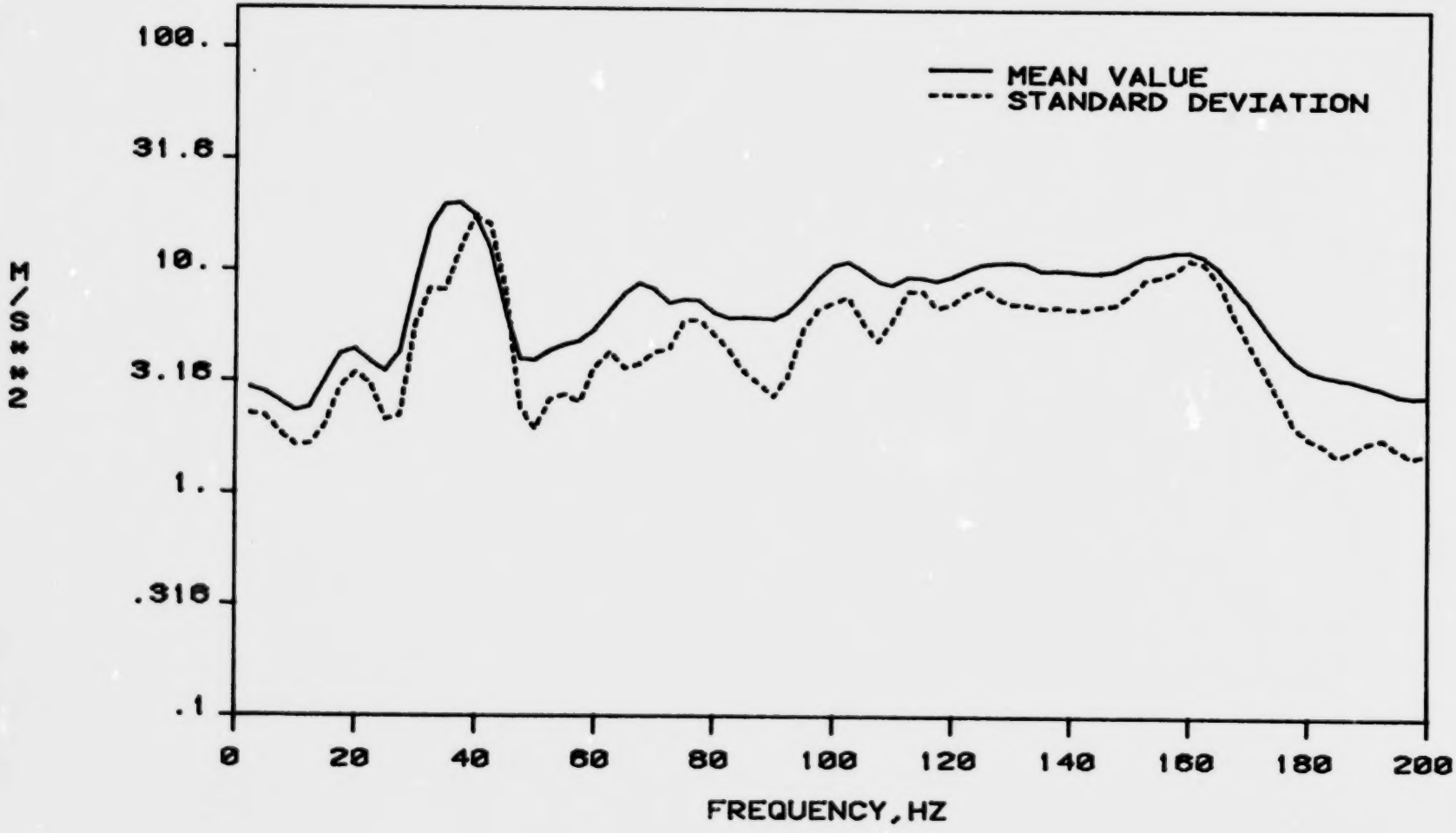


Figure 3.10d R.M.S. ACCELERATION SPECTRA FOR FIVE STOPER DRILLS (B,38S)

drills of the same type are presented. Again the similarity of the individual and mean spectra indicates the existance for stopers of type B of a well defined vibration spectrum signature essentially independent of operating conditions (at least at a given mine site).

Comparing the average spectra for jack legs (Figure 3.3c) and stopers (Figure 3.10c) it may be seen that the acceleration level at the firing frequency for the jack leg drill is approximately 50% higher than for the stoper drill.

During testing of each drill the air pressure to the drill was measured using a needle valve inserted in the hose near the drill. The pressures varied from 75 to 95 psi but no correlation between pressure and vibration level was discernable.

Also during drilling the time taken to drill a particular depth was noted. From these results the average drilling rate for jack leg drills was found to be .56 minutes/foot and for the stoper drills .63 minutes/foot. Then from mine records spanning the period January - July 1982 inclusive the average footage drilled per man shift by the miners at the Westmin mine was found to be:

	Jack Leg Drill	Stoper Drill
Stope miner	48	32
Drift miner	108	28
Raise miner		134

Thus the raise miner would be drilling for at least 134x.63 = 84.4 minutes per man shift. In fact he would be likely drilling for somewhat longer periods as the figures used do not account for the time taken to collar difficult holes and for the time taken in extracting the steel. It would thus appear that a raise miner may be subjected to vibrations for 1.5 hours per man shift. This figure

will be used in Section 3.5 in assessing the provisions of ISO DIS 5349. The figure for the drift miner is 78.1 minutes per man shift and thus an overall time of 1.5 hour is not unreasonable for this driller as well. It must also be recognized that the stoper driller is likely to spend much of the drilling time holding the hose, and that with both stopers and jack legs the miner will sometimes release the drill entirely.

3.4 Results of Rock Drill Tests from Kimberley Mine

At the Kimberley mine the stoper drill is more commonly used than the jack leg and at this mine 7 stopers were tested and 10 jack legs. Emphasis was placed upon obtaining jack leg results because of the higher acceleration levels associated with these drills. In this mine two brands of drill are commonly used and thus it was possible to make comparisons between the vibration levels produced by each type of drill.

In Figures 3.11 a-d and 3.12 a-d the results of measurements taken on 4 jack leg drills of type A and 4 jack leg drills of type B respectively are presented. Then in Figures 3.13 a-b a comparison of their mean levels is given. The spectra have distinct forms with drill B having resonant peaks close to 250 and 700 Hz whereas drill A appears to have a resonant peak close to 350 HZ but has higher vibration levels than B above 700 Hz. At the firing frequency, which is somewhat higher for drill B the acceleration levels are practically the same at approximately 30 m/s^2. Comparison of the results presented in Figure 3.13a and those in Figure 3.3c show close agreement between the spectra recorded at the two different mine sites for drill type B.

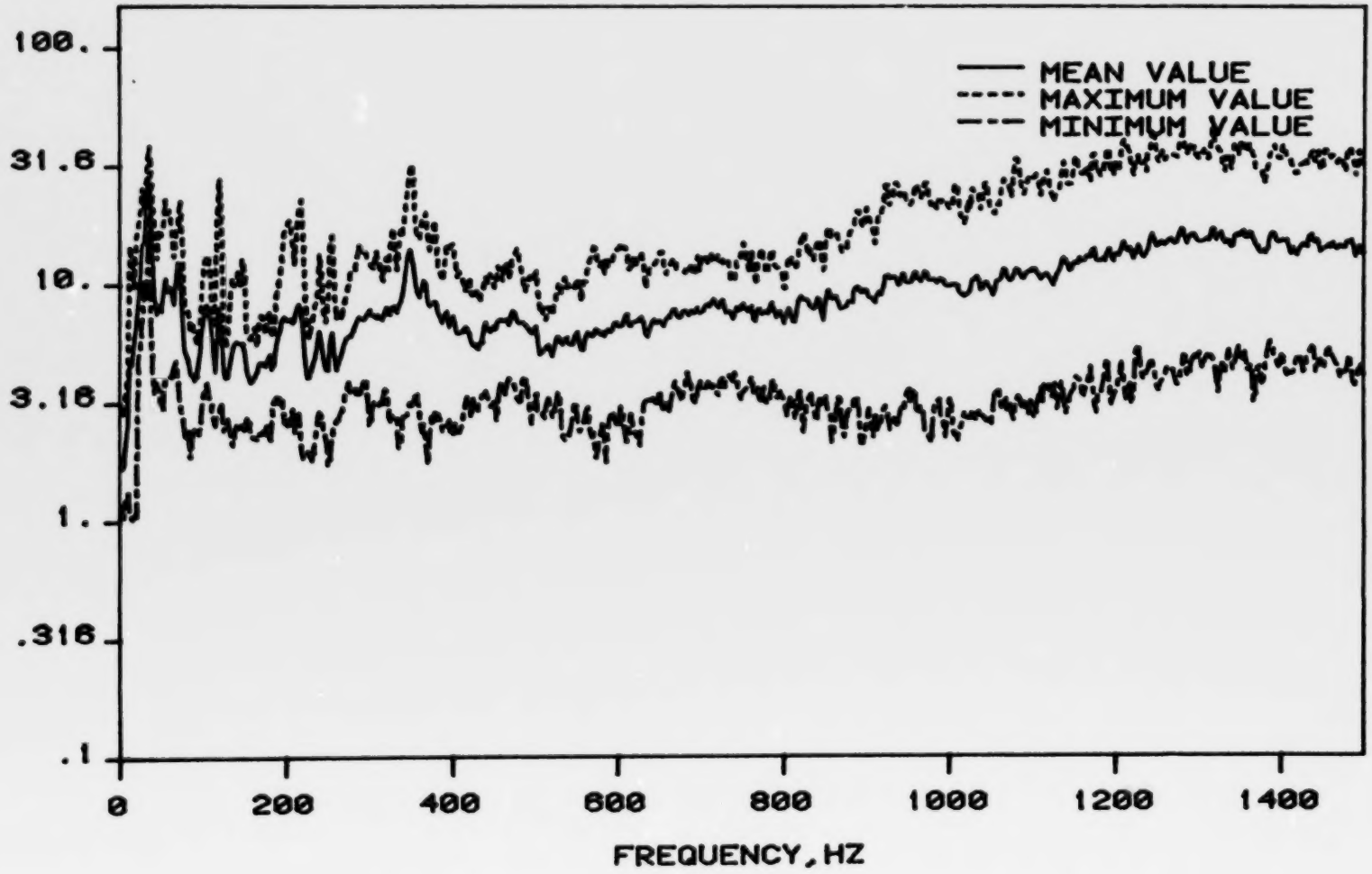


Figure 3.11a R.M.S. ACCELERATION SPECTRA FOR TYPE A JACK LEG DRILL (4D,8S)

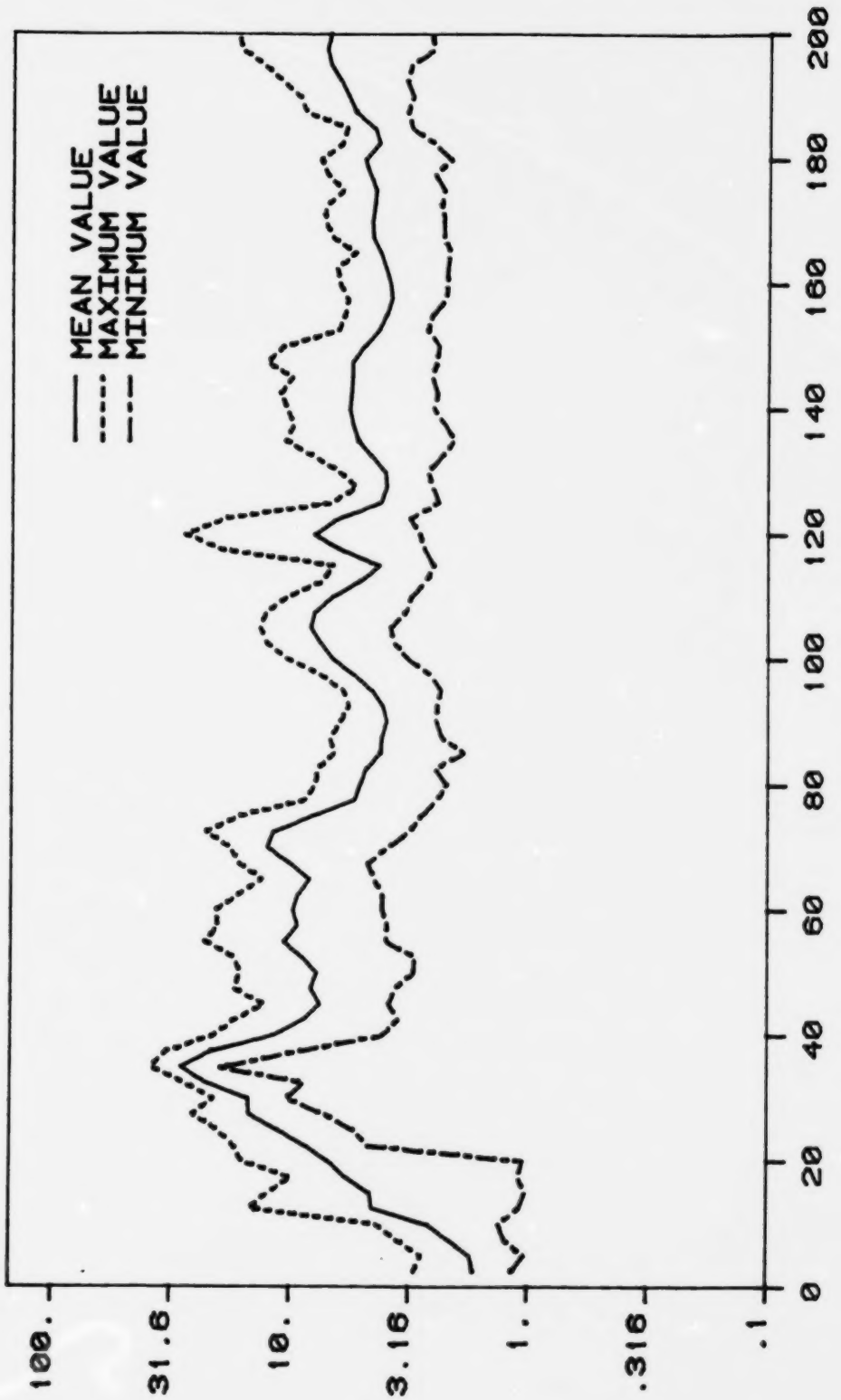


Figure 3.11b R.M.S. ACCELERATION SPECTRA FOR TYPE A JACK LEG DRILL (4D,8S)

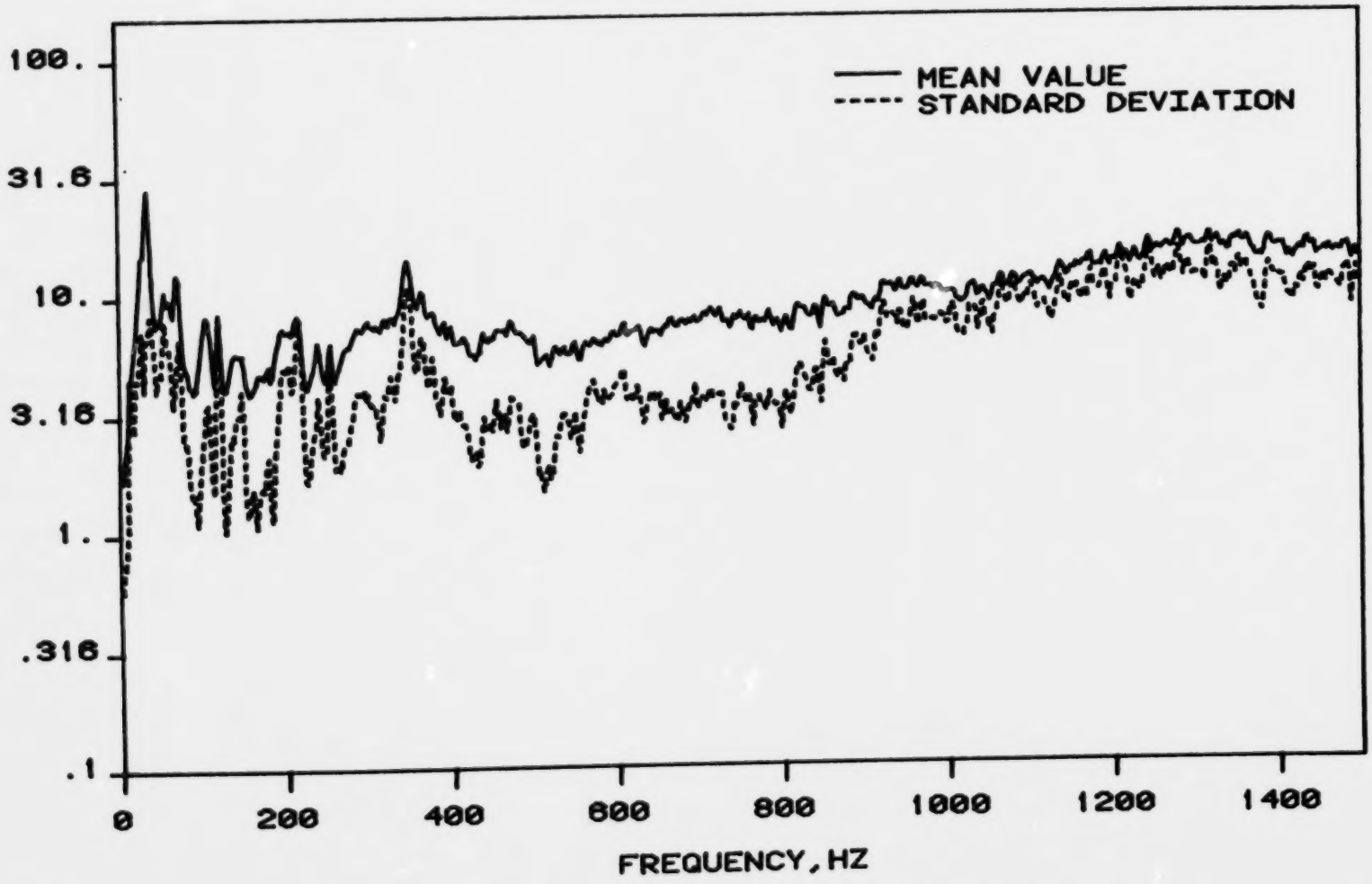


Figure 3.11c R.M.S. ACCELERATION SPECTRA FOR TYPE A JACK LEG DRILL (4D,8S)

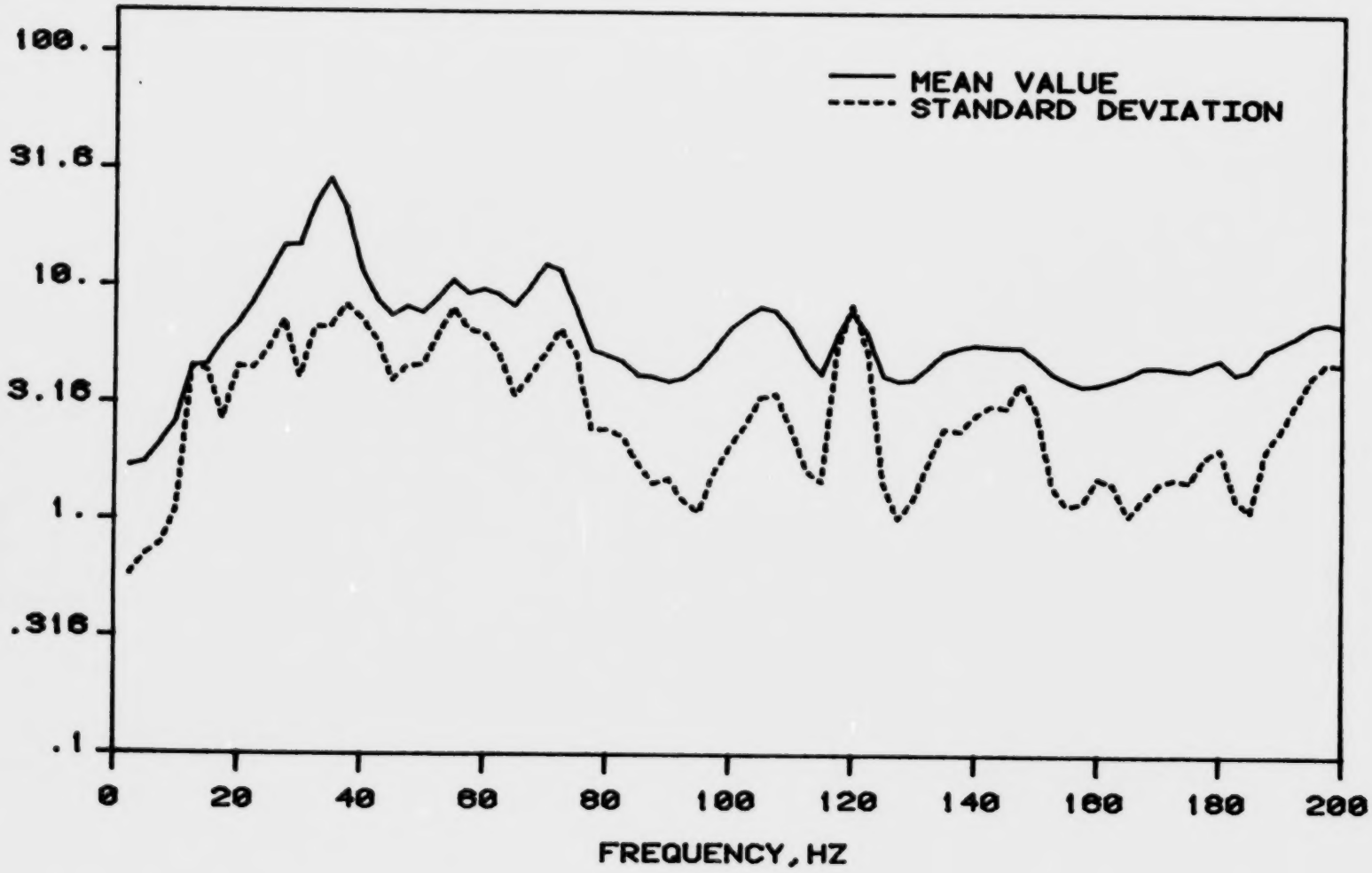


Figure 3.11d R.M.S. ACCELERATION SPECTRA FOR TYPE JACK LEG DRILL (4D,8S)

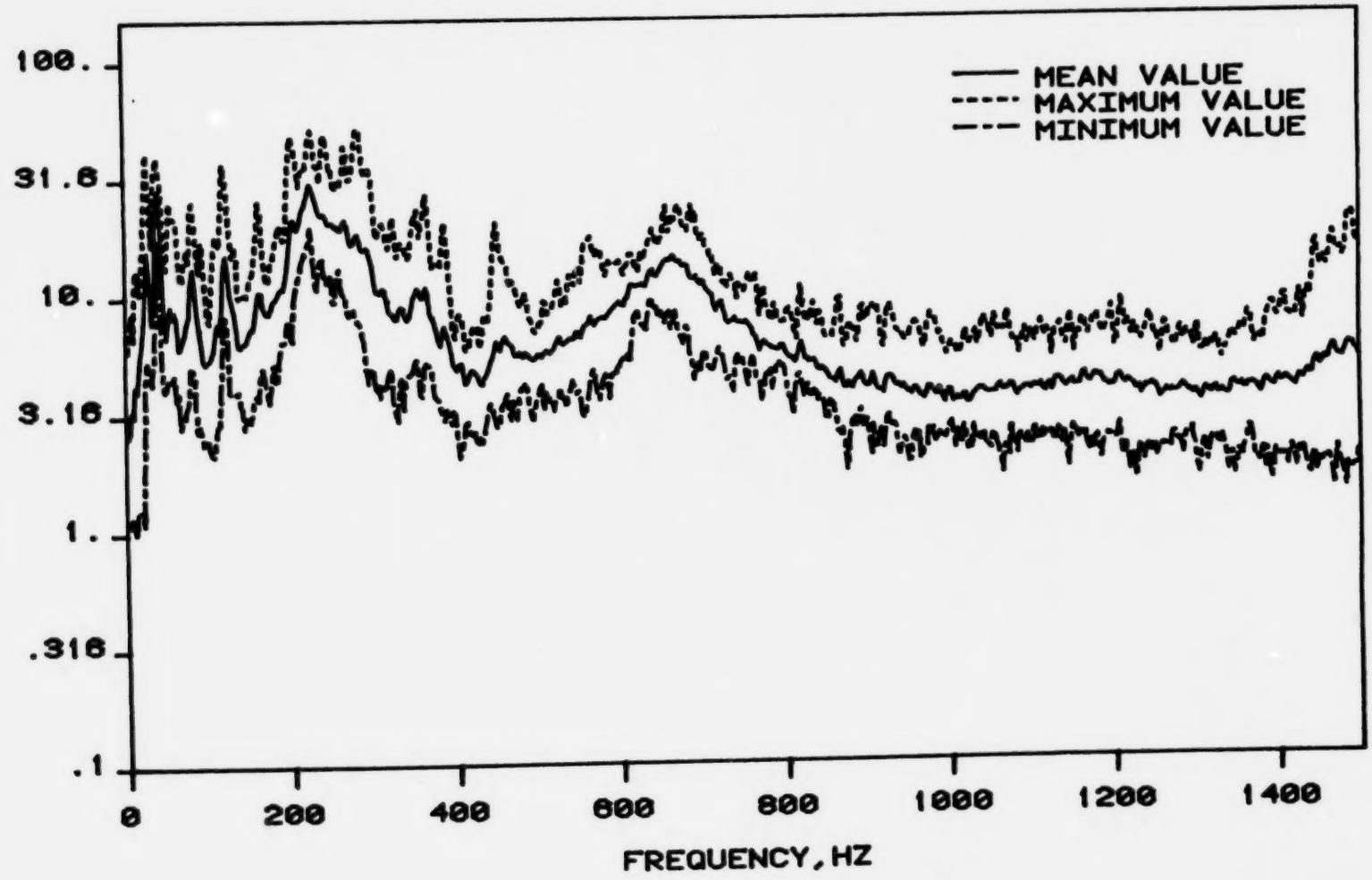


Figure 3.12a R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

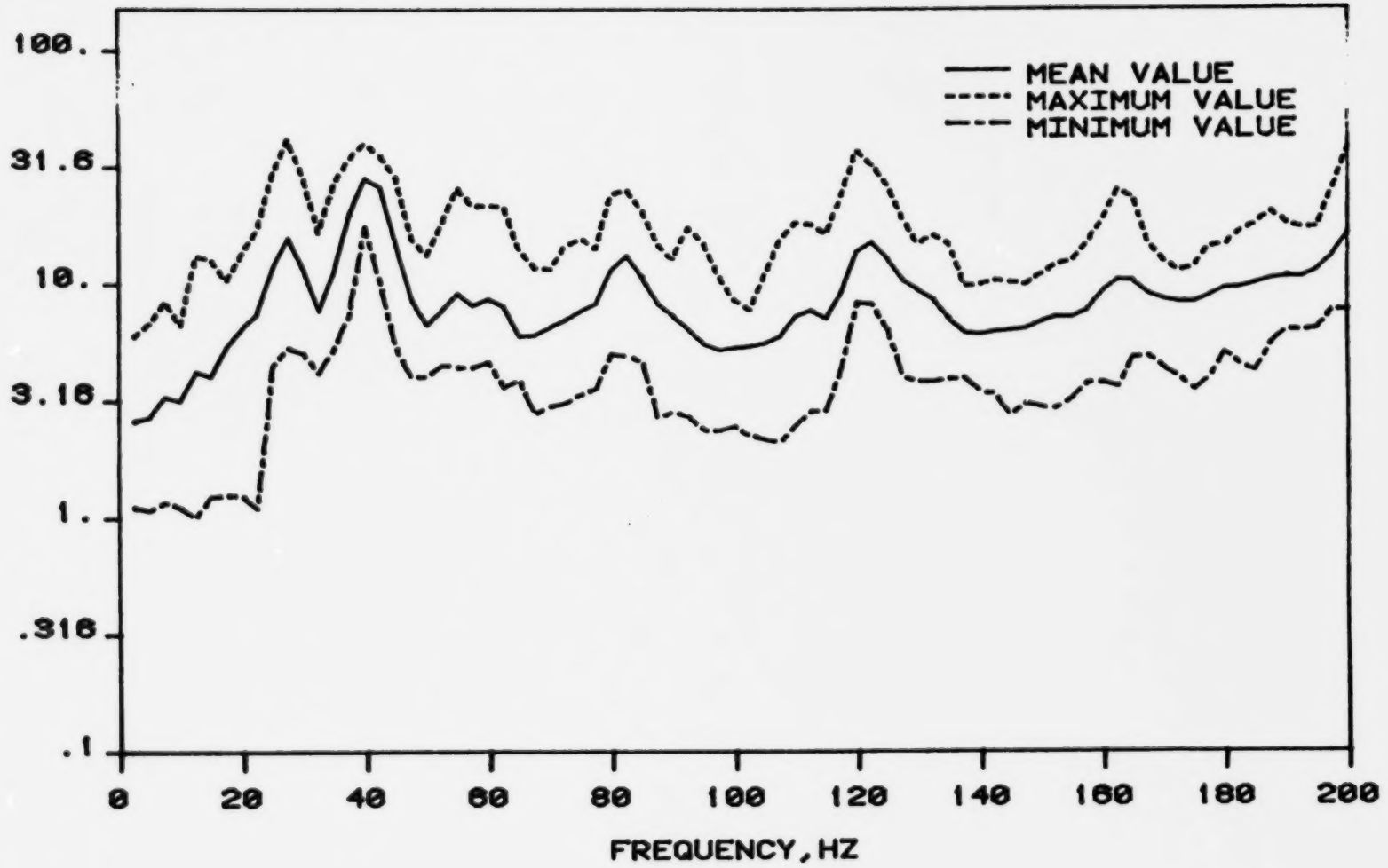


Figure 3.12b R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

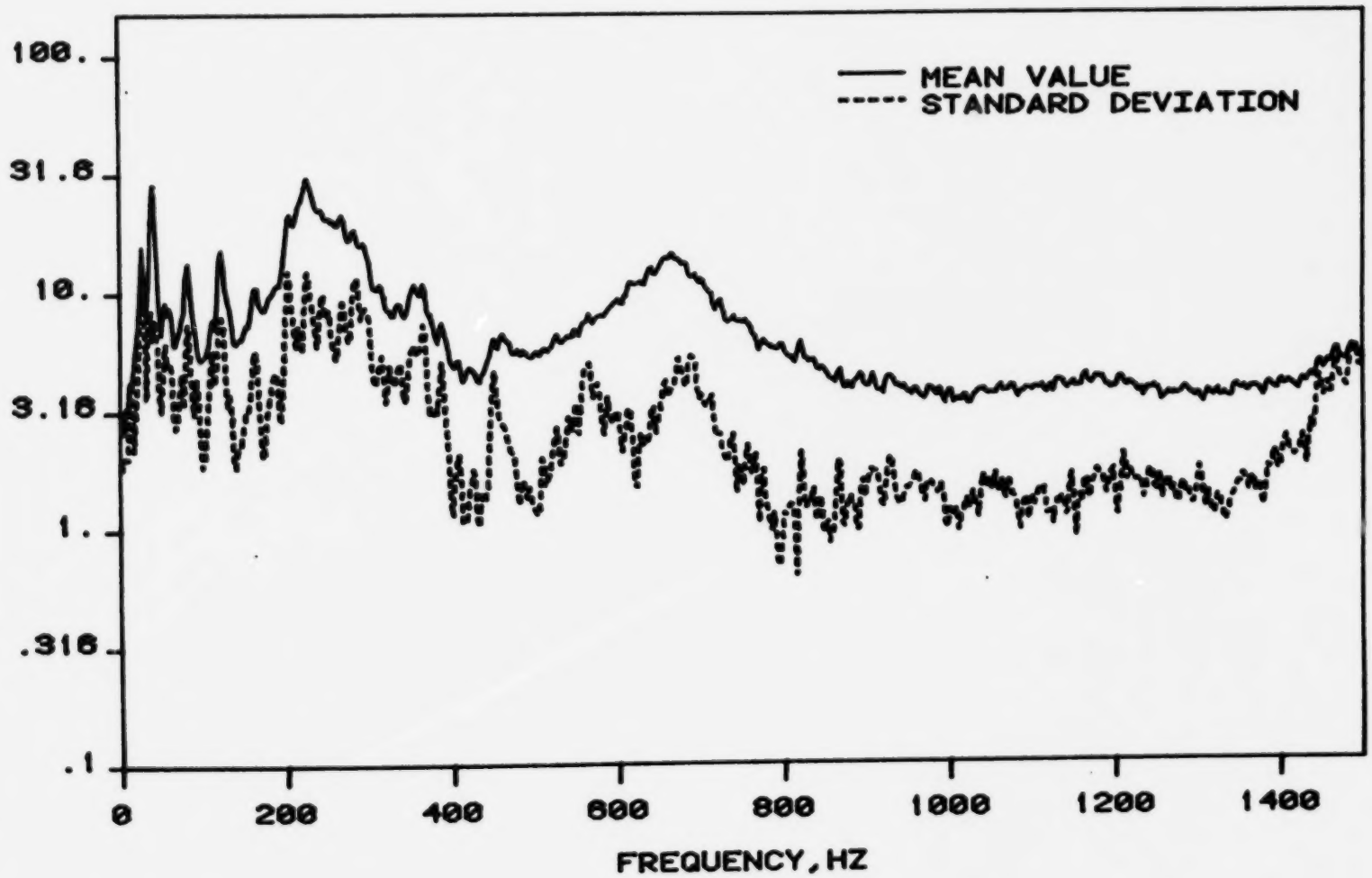


Figure 3.12c R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

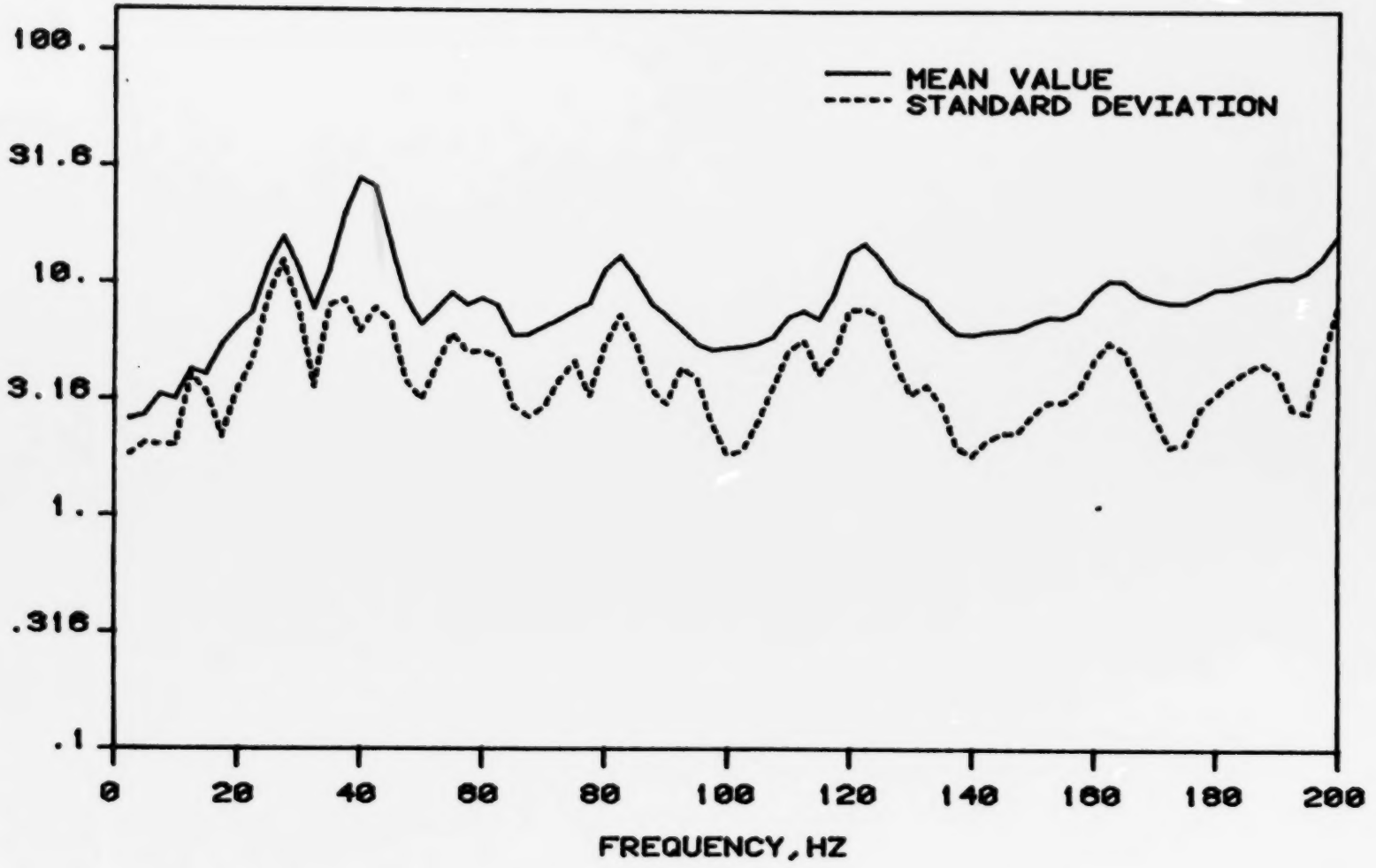


Figure 3.12d R.M.S. ACCELERATION SPECTRA FOR TYPE B JACK LEG DRILL (4D,8S)

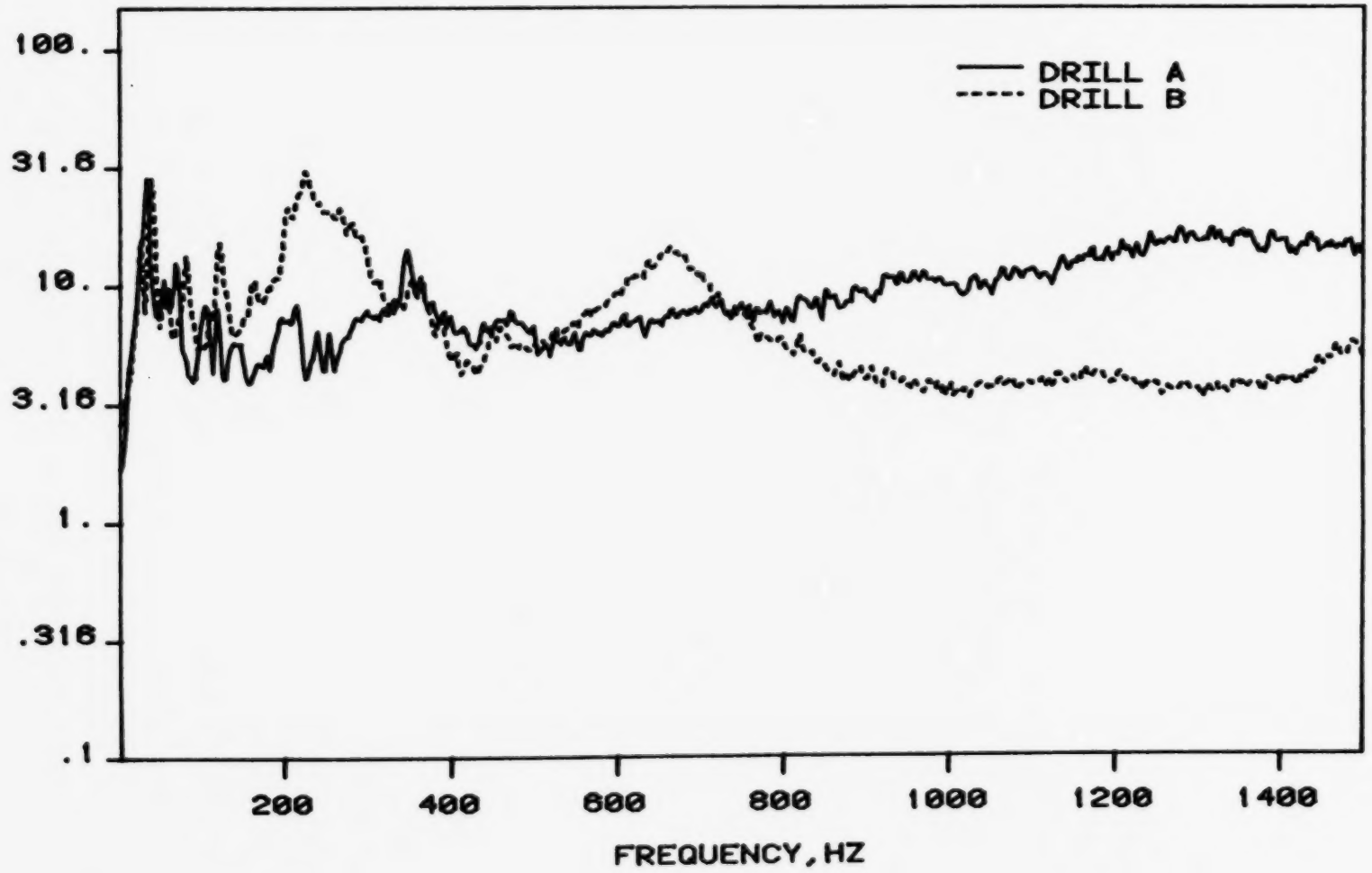


Figure 3.13a COMPARISON OF R.M.S. ACCELERATION SPECTRA BETWEEN JACK LEG DRILLS OF TYPE A AND B (8D,16S)

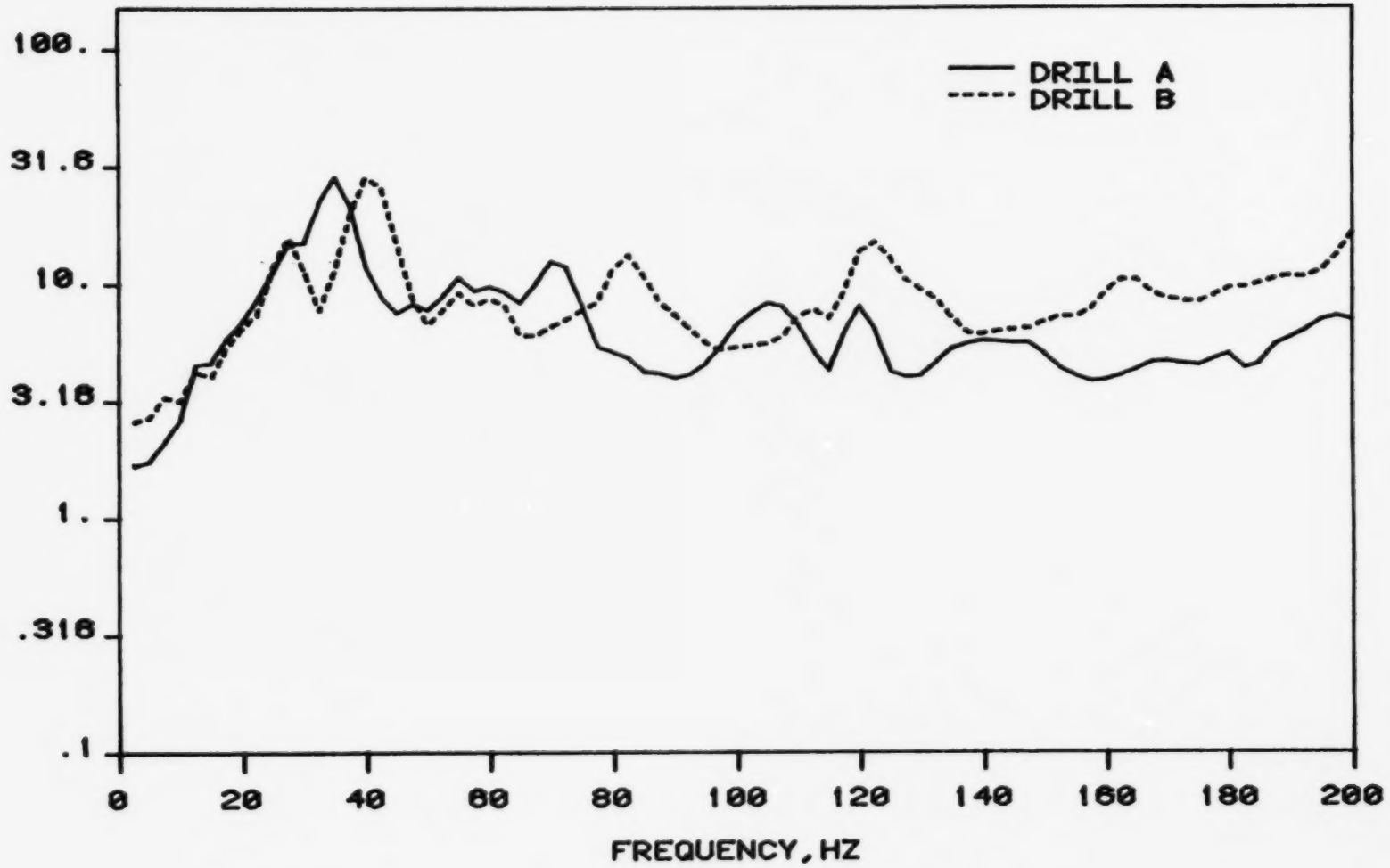


Figure 3.13b COMPARISON OF R.M.S. ACCELRATION SPECTRA BETWEEN JACK LEG DRILLS OF TYPE A AND B (4D,8S)

Individual samples of two other types of jack leg (not commonly used in the mine) were also obtained. These results are displayed in Figure 3.14. Note however that such spectrum represents only one sample.

With stopers, drilling is often performed from a timber platform, either built up from the ground, or attached to the walls of a raise. Such a support system is of course less rigid than that used when drilling from a rock base, and the possibility arises that the flexibility (dynamic characteristic) of the timber supports may affect the level of vibration. To this end Figures 3.15 a-d and 3.16 a-d present the results of tests for stoper drills with timber and rock supports respectively. In both cases the drills used were of type A. In Figure 3.17 a comparison is presented that illustrates the effect of the support condition. As may be seen in the range up to 500 Hz, although the shape of the spectrum is the same, the vibration levels associated with the timber supported drills are significantly lower.

In practise when drilling with a stoper the miner may hold the hose rather than the drill handle after the hole has been collared. Figures 3.18 a-d present the results of acceleration levels recorded on the hose in directions at right angles to the centre line of the hose. The results indicate peaks at the firing frequency and at approximately 200 Hz with peak level at the firing frequency of the same magnitude as the timber supported stoper, but at higher frequencies the levels are much reduced.

The effect of steel length on the vibration level of stopers was, as in the case of jack leg drills, not found to be significant. Figures 3.19 a-b present a representative comparison of the results

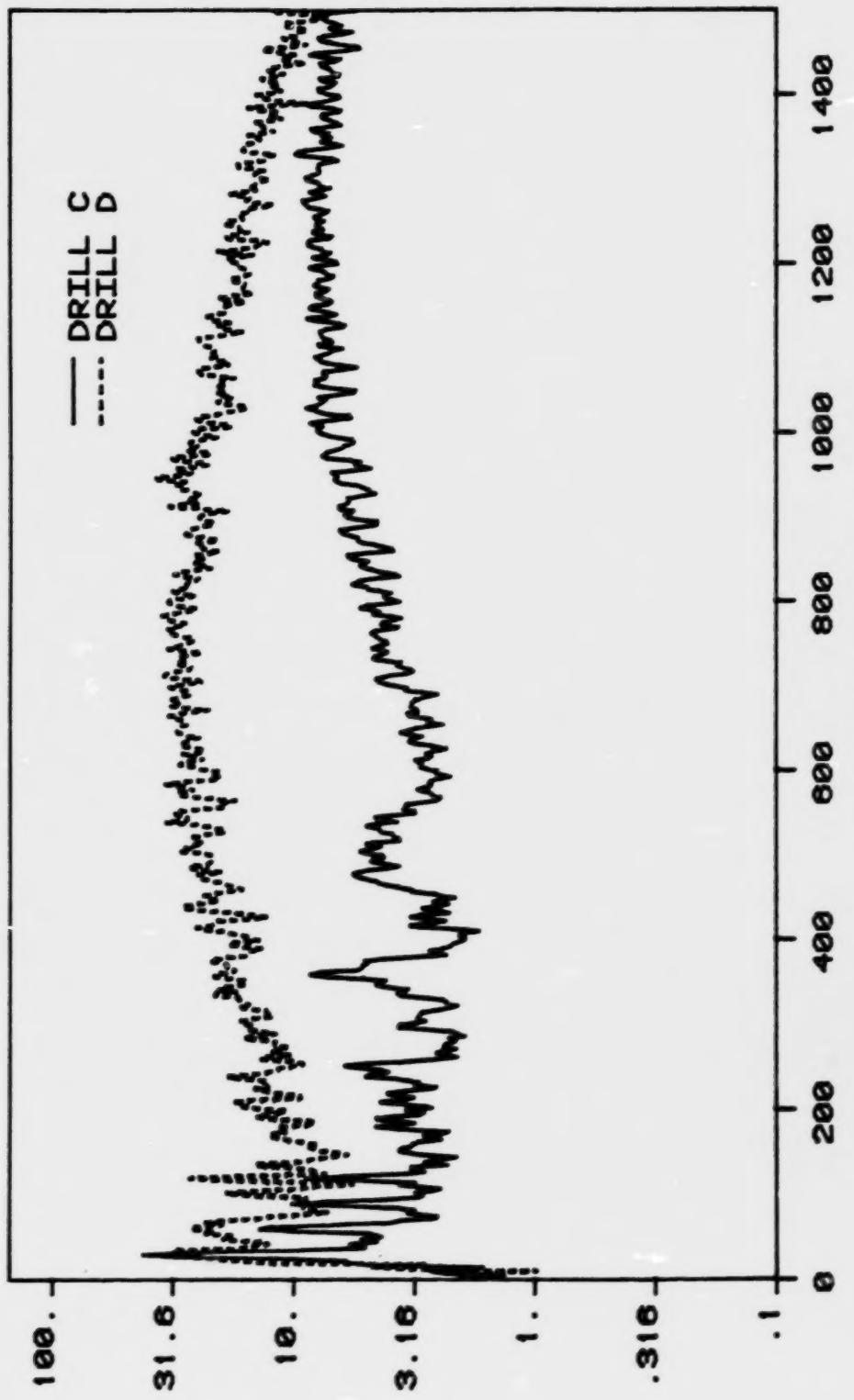


Figure 3.14 COMPARISON OF R.M.S. ACCELERATION SPECTRA BETWEEN JACK LEG DRILLS OF TYPE C AND D (2D,2S)

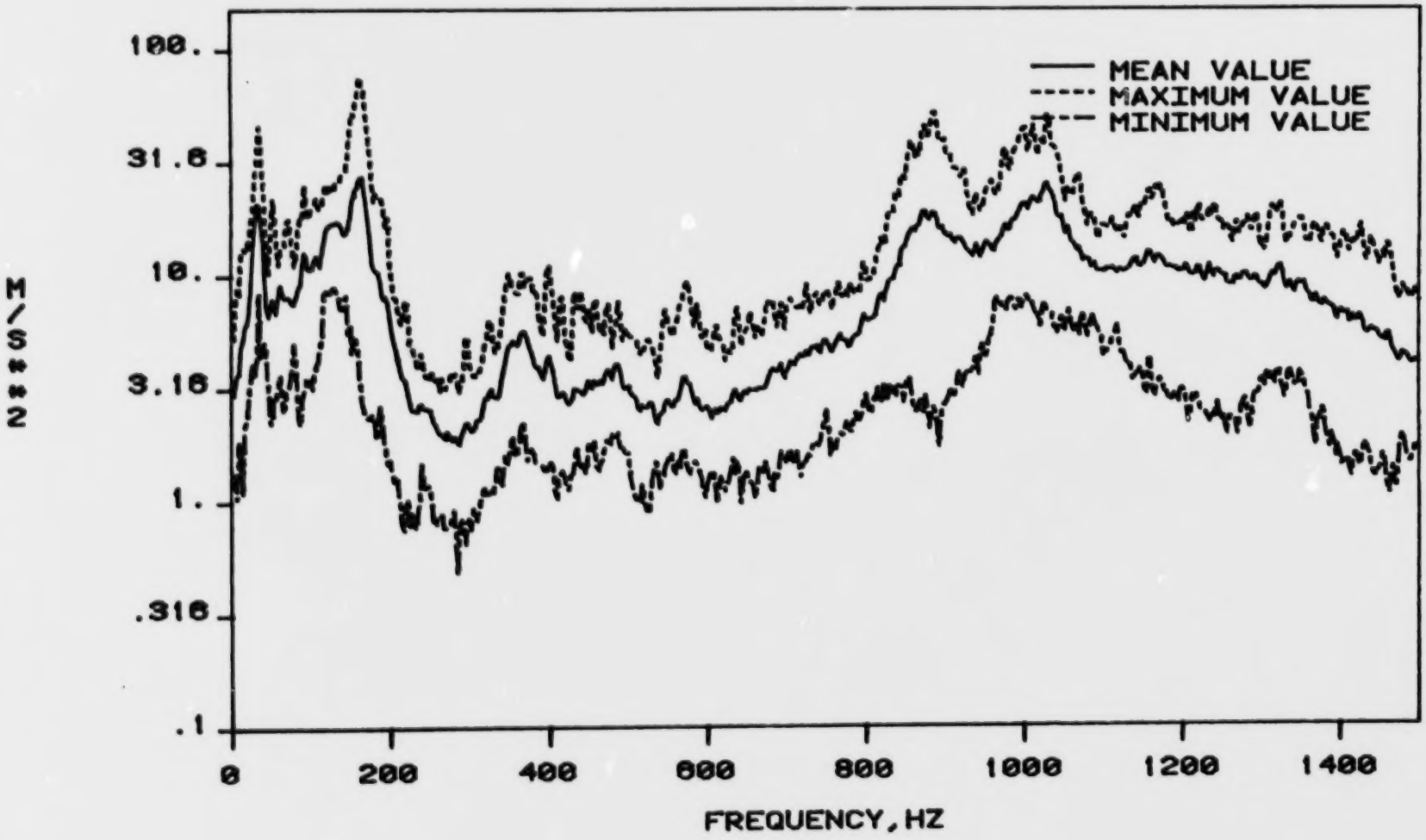


Figure 3.15a R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS (A,3D,10S)

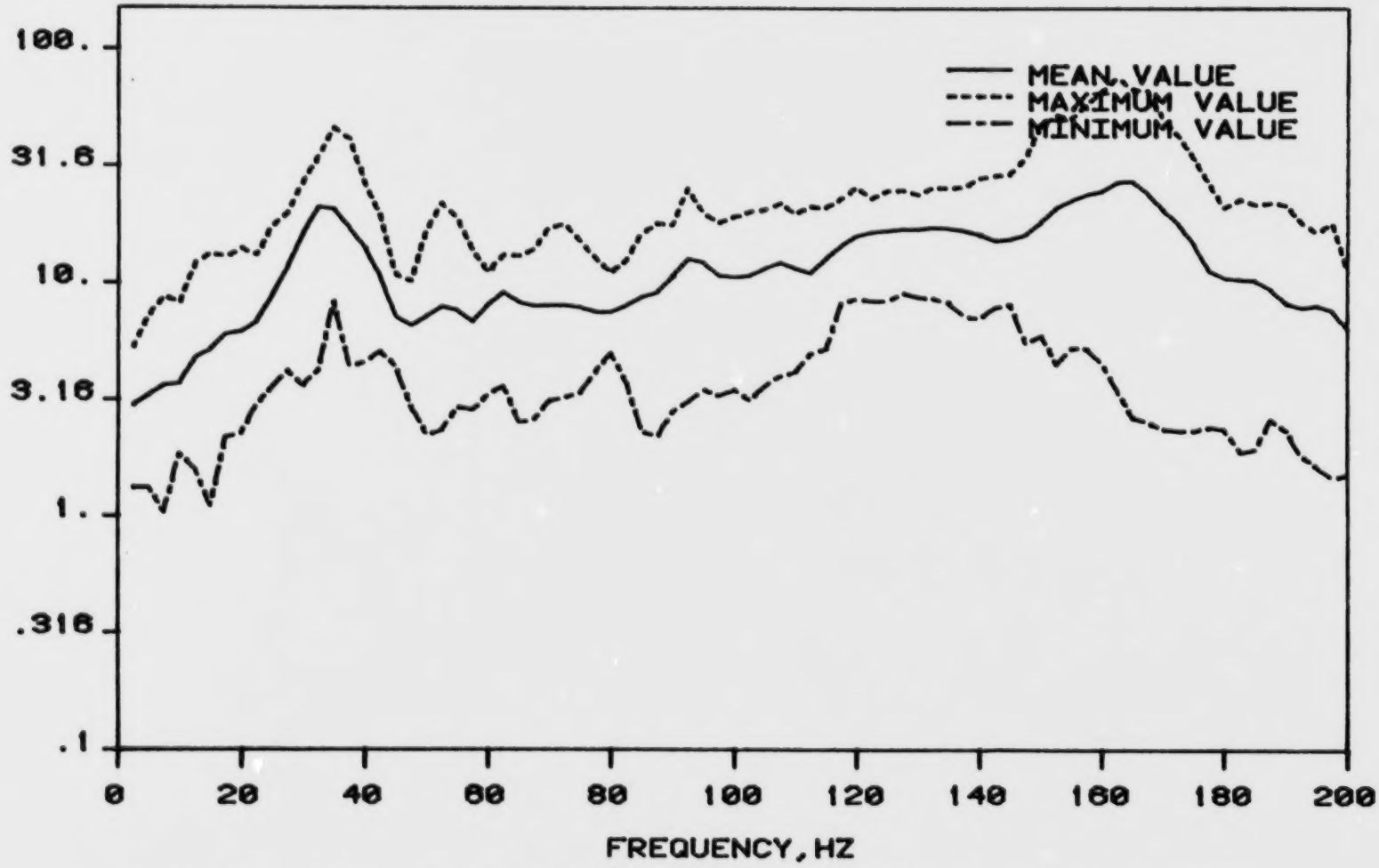


Figure 3.15b R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS (A,3D,10S)

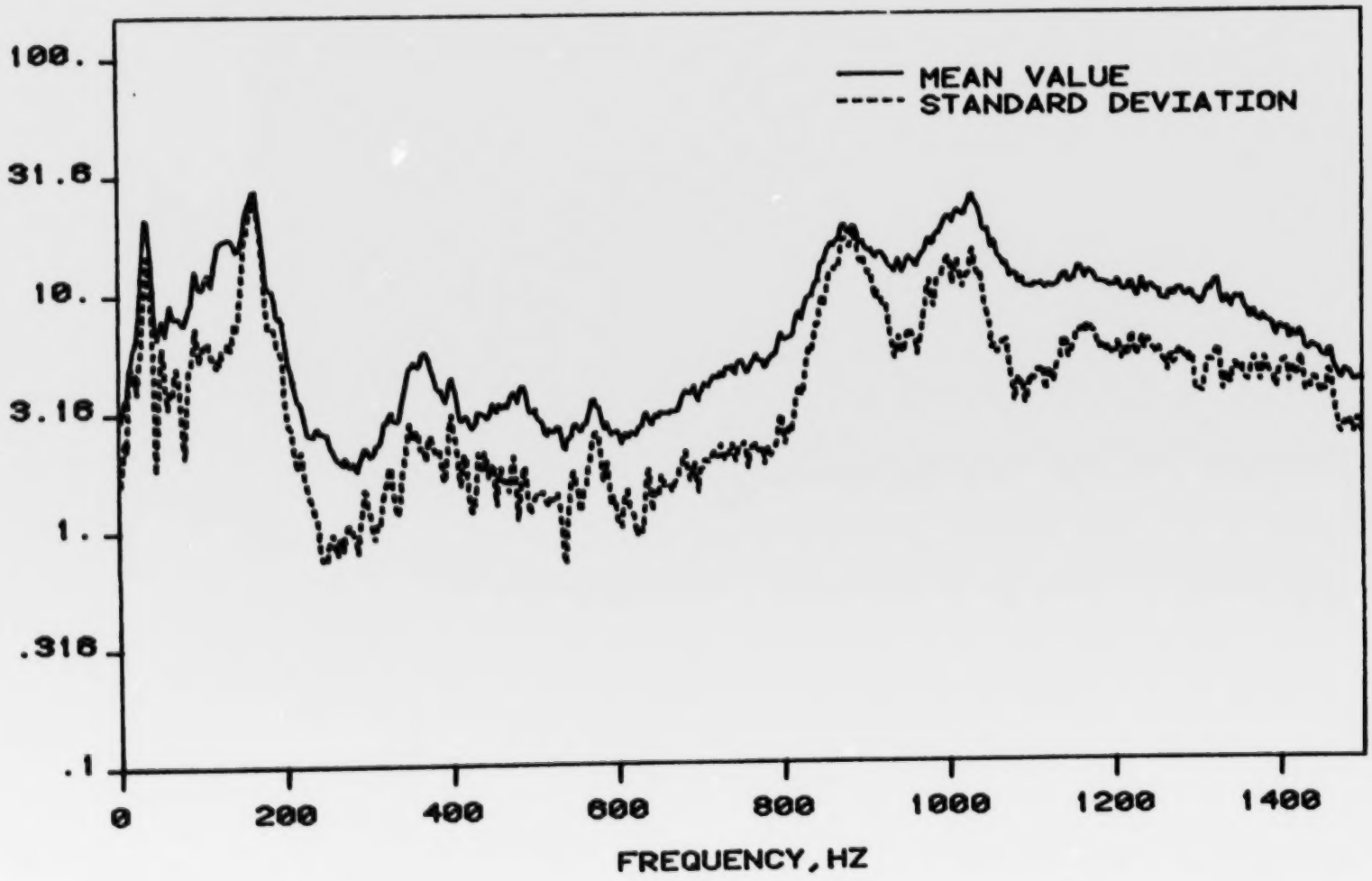


Figure 3.15c R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS (A,3D,10S)

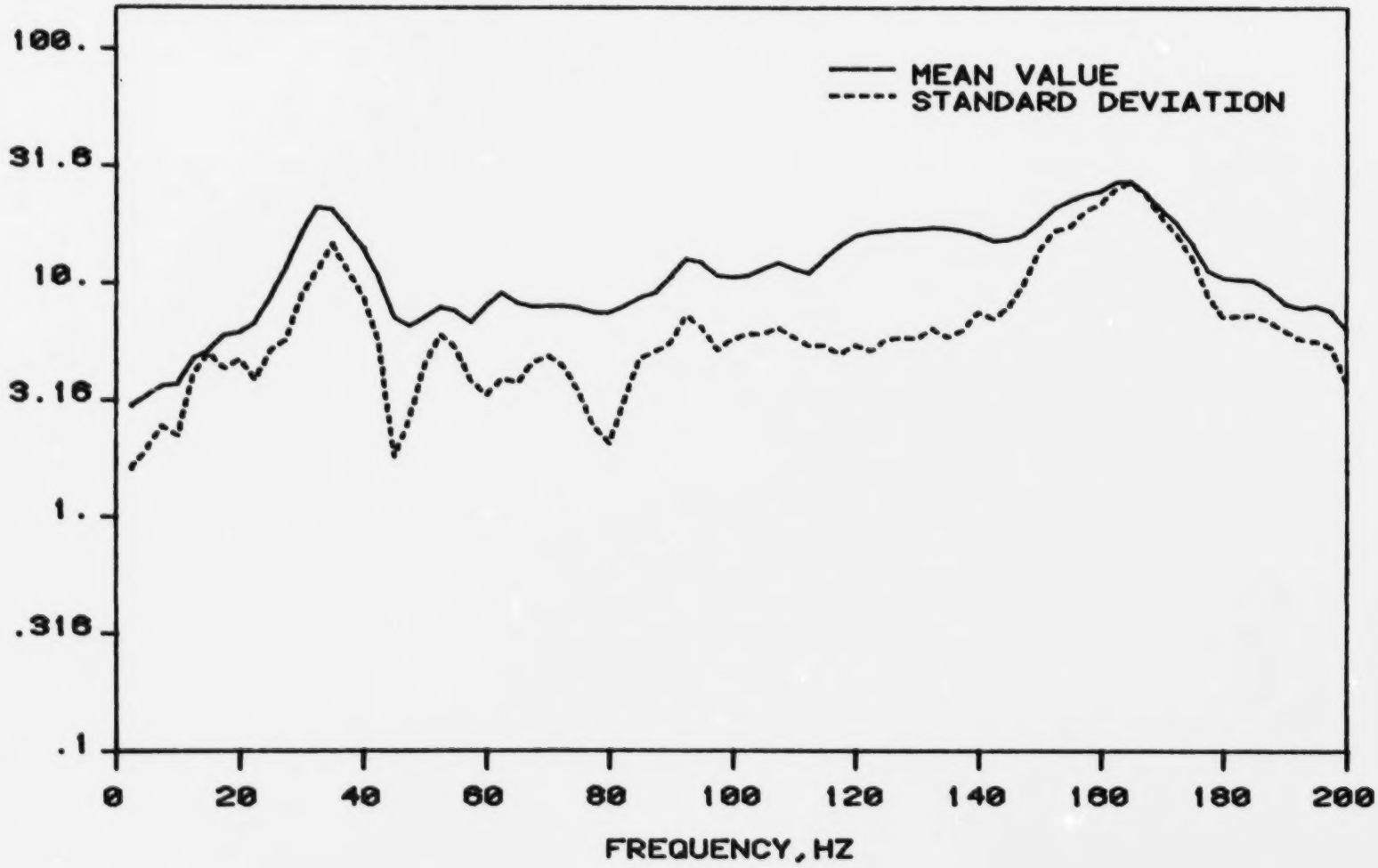


Figure 3.15d R.M.S. ACCELERATION RECORDS FOR TIMBER SUPPORTED STOPER DRILLS(A,3D,10S)

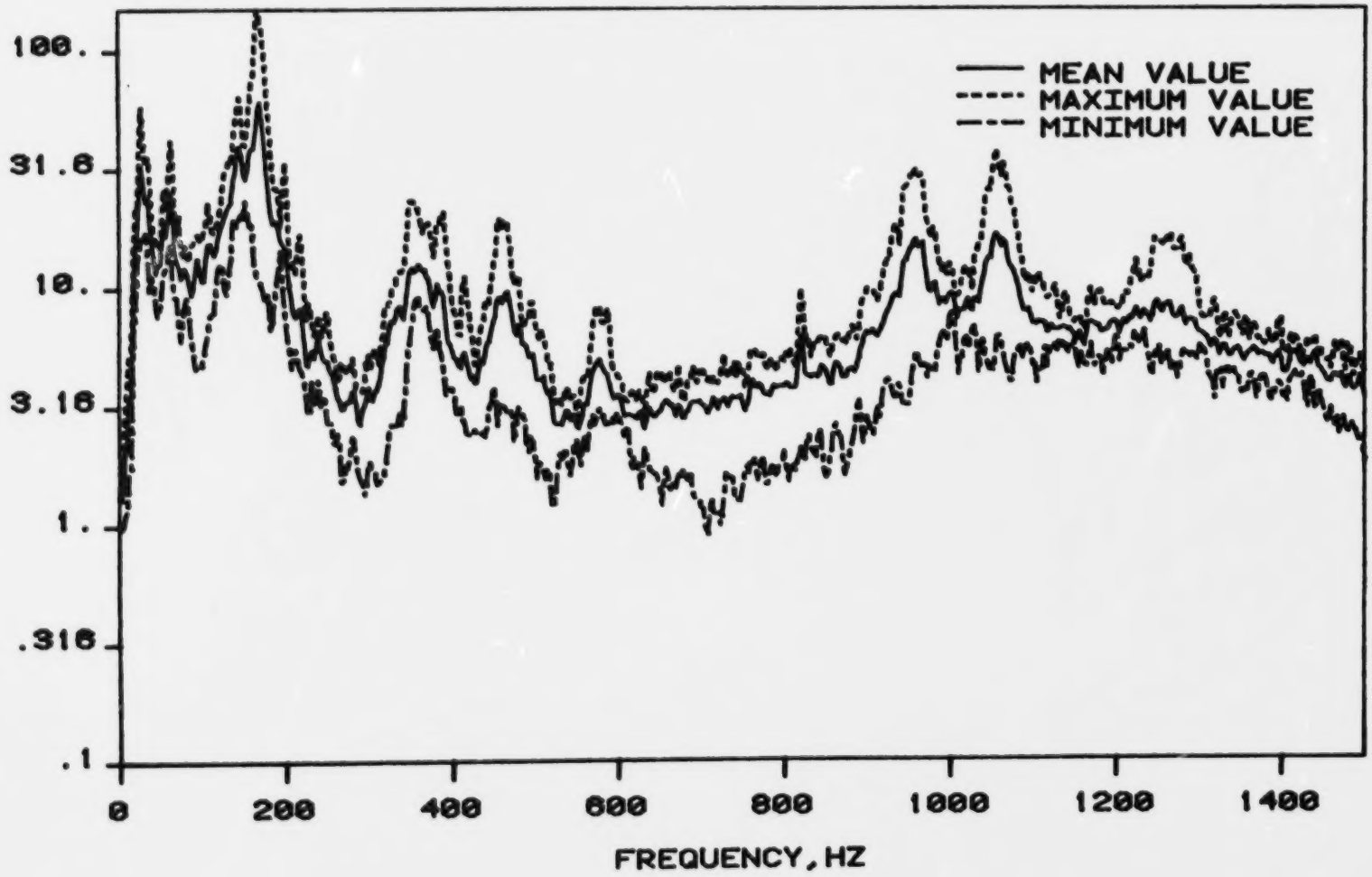


Figure 3.16a R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

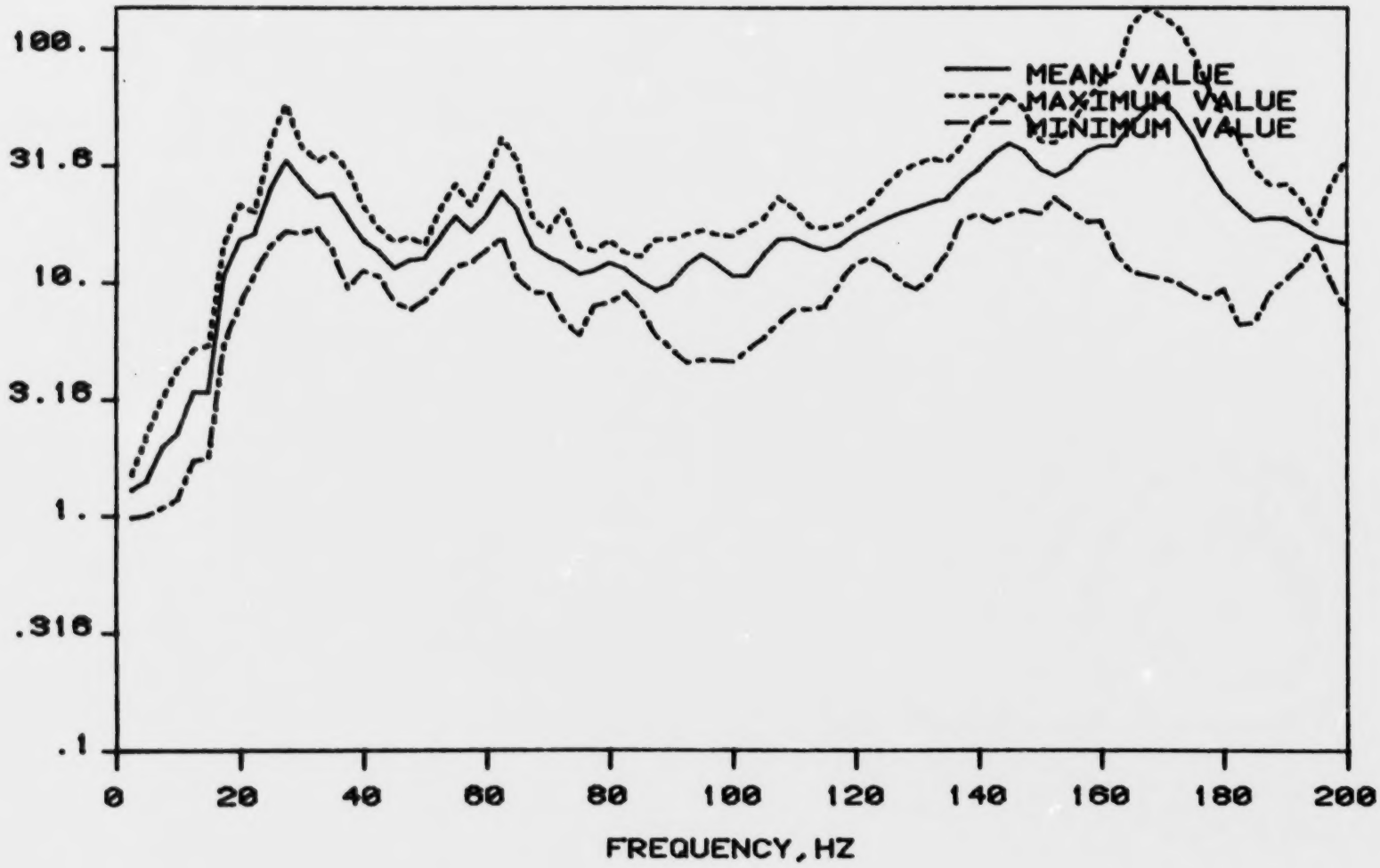


Figure 3.16b R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

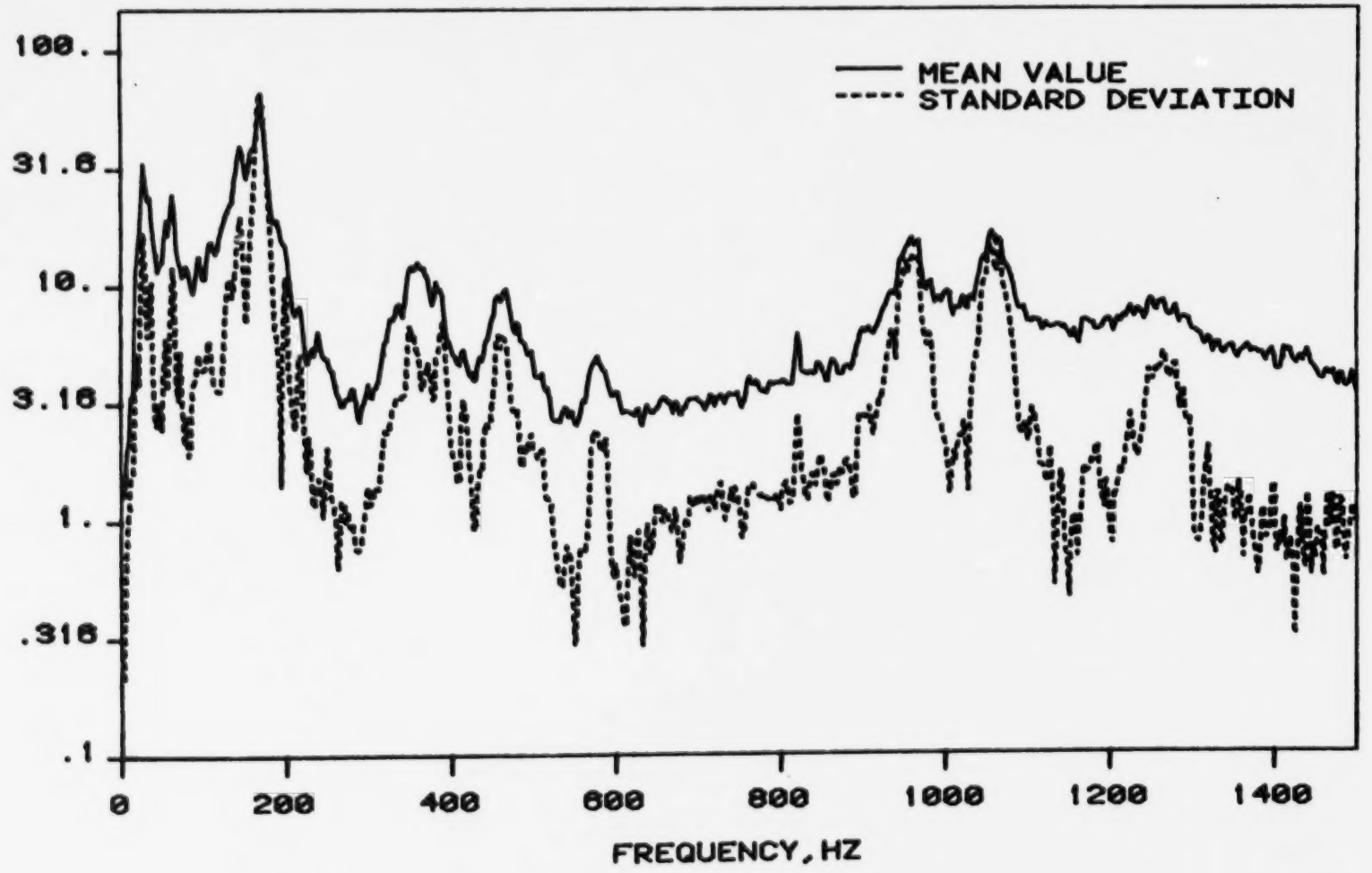


Figure 3.16c R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

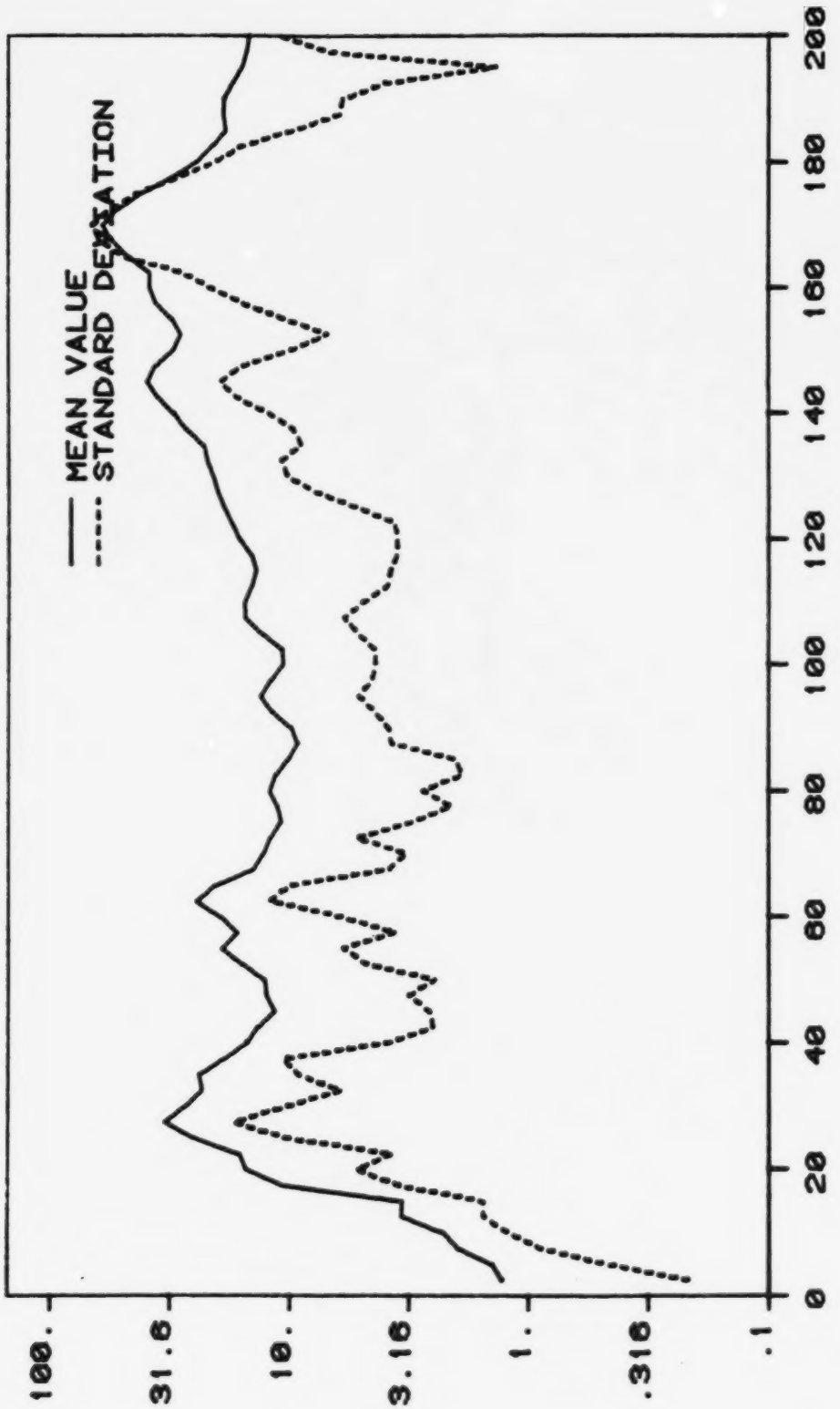


Figure 3.16d R.M.S. ACCELERATION SPECTRA FOR ROCK SUPPORTED STOPER DRILLS (A,2D,5S)

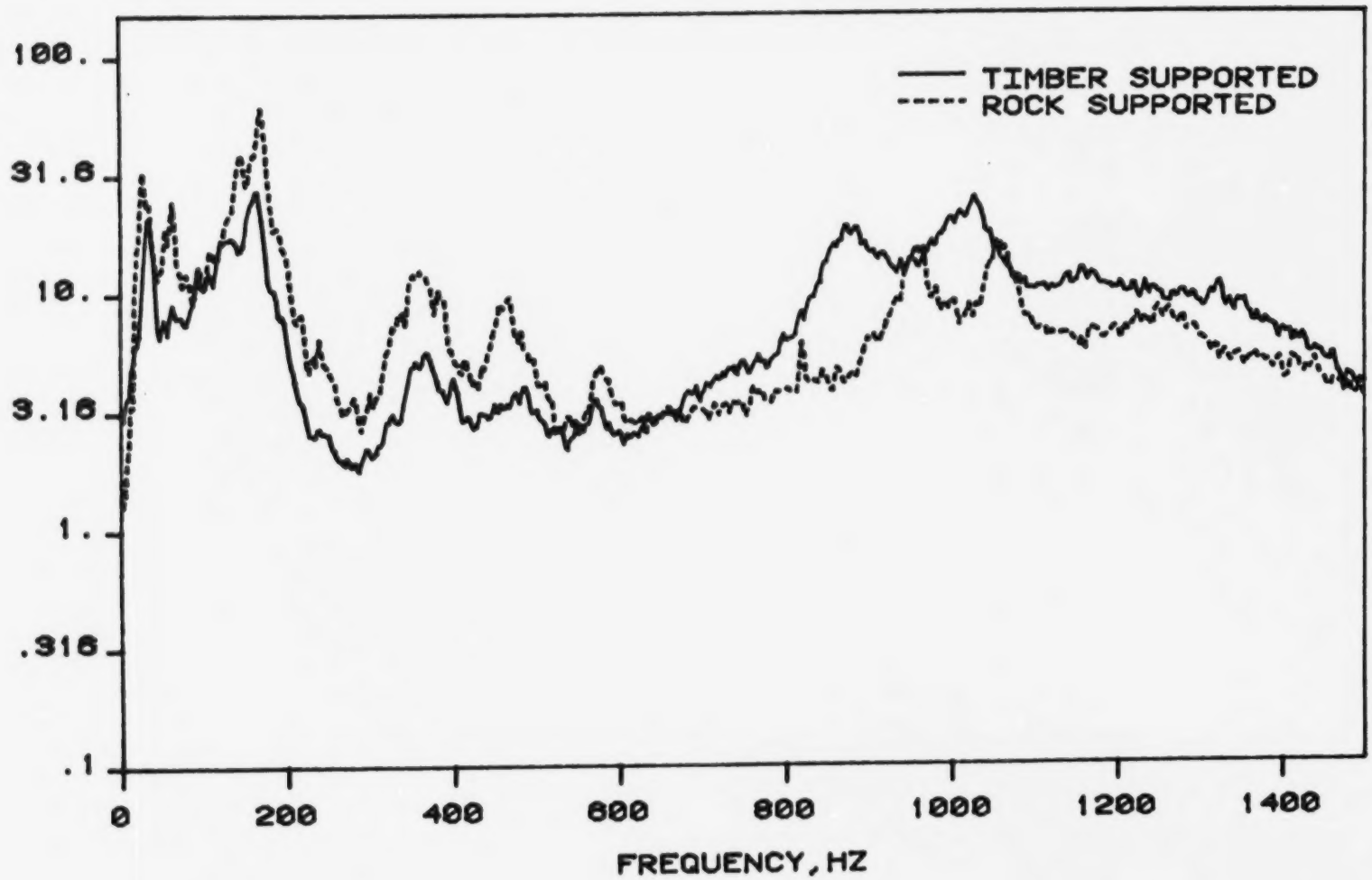


Figure 3.17 COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR ROCK AND TIMBER SUPPORTED STOPER DRILLS (A,4D,15S)

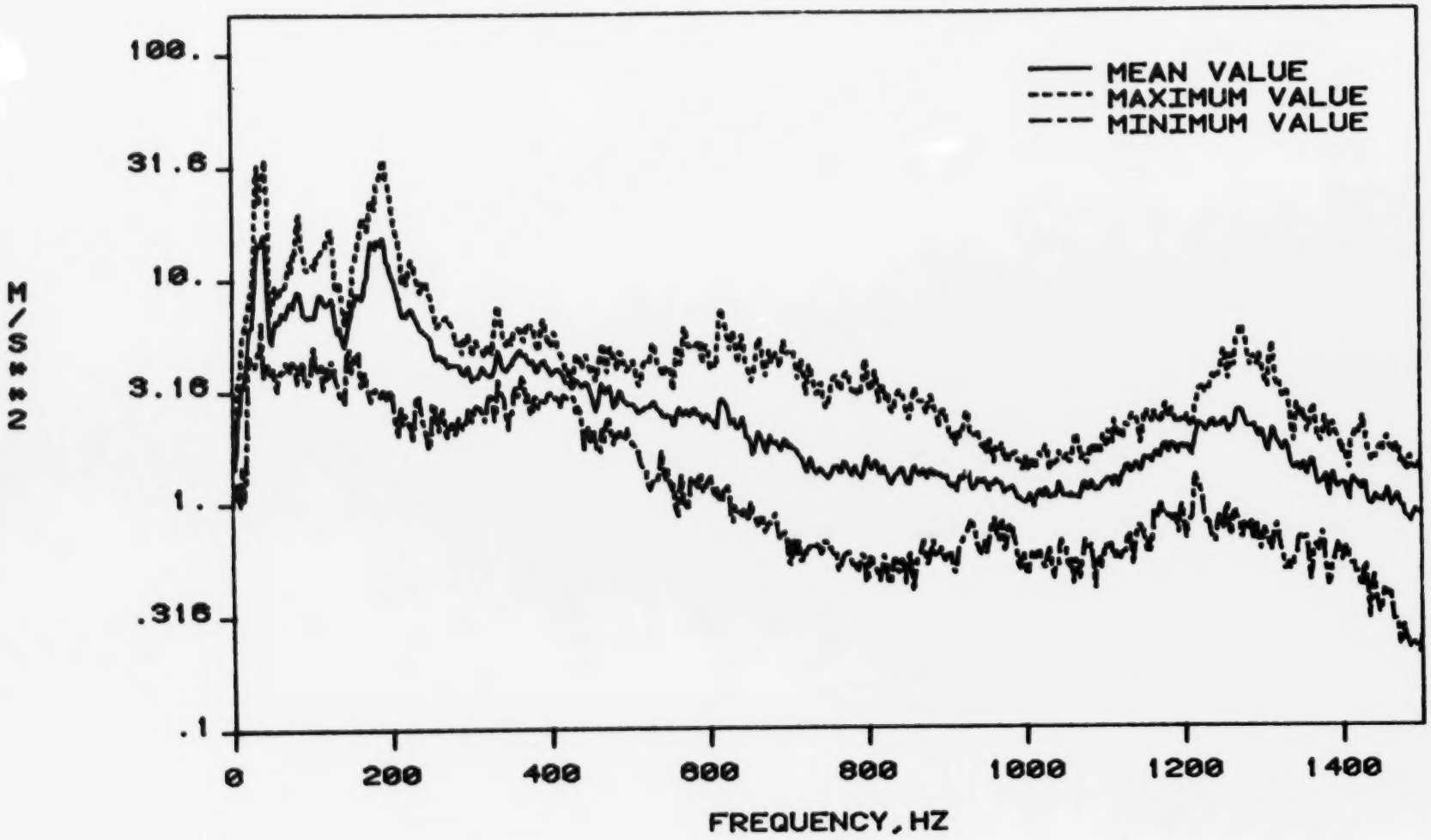


Figure 3.18a R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

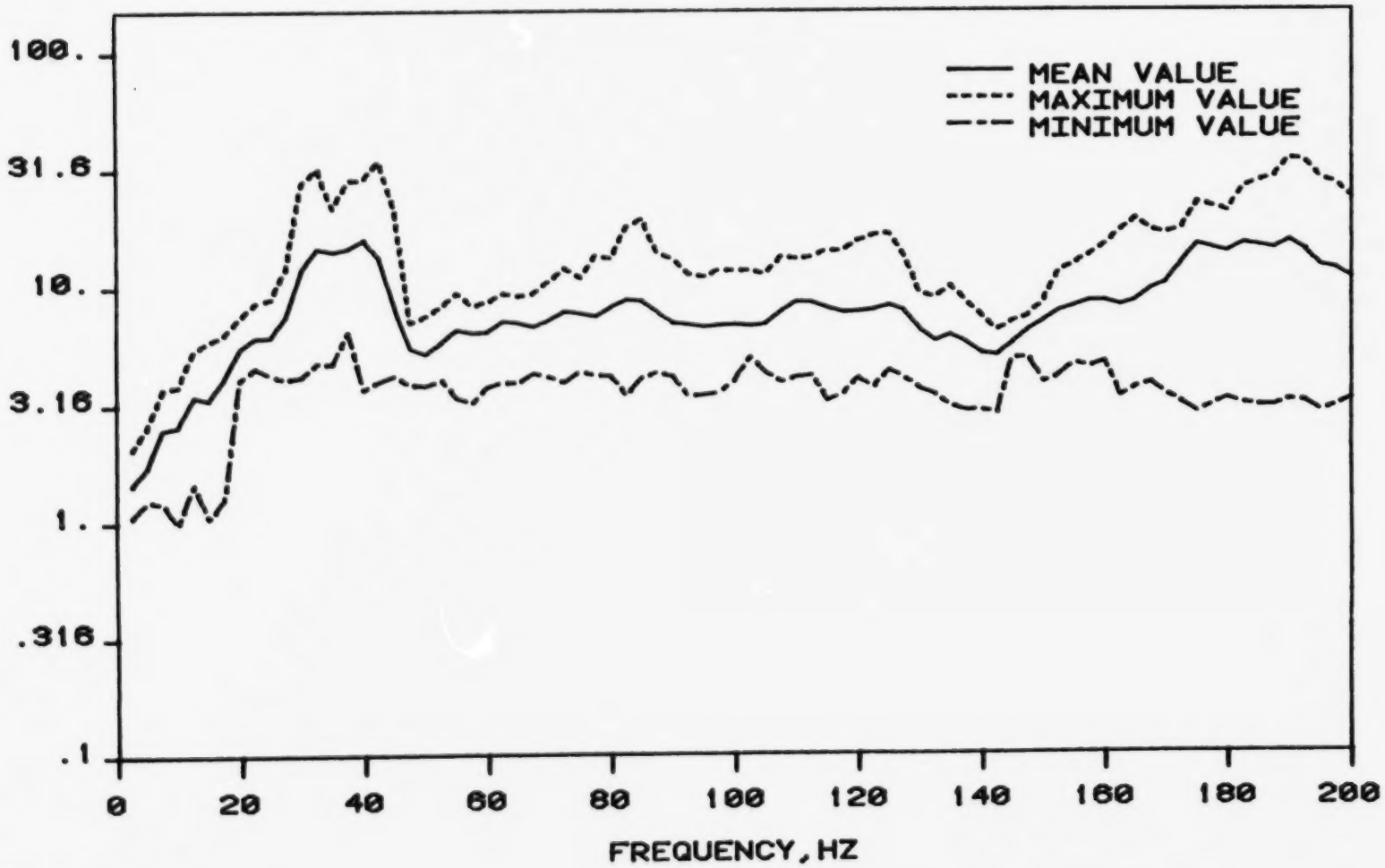


Figure 3.18b R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

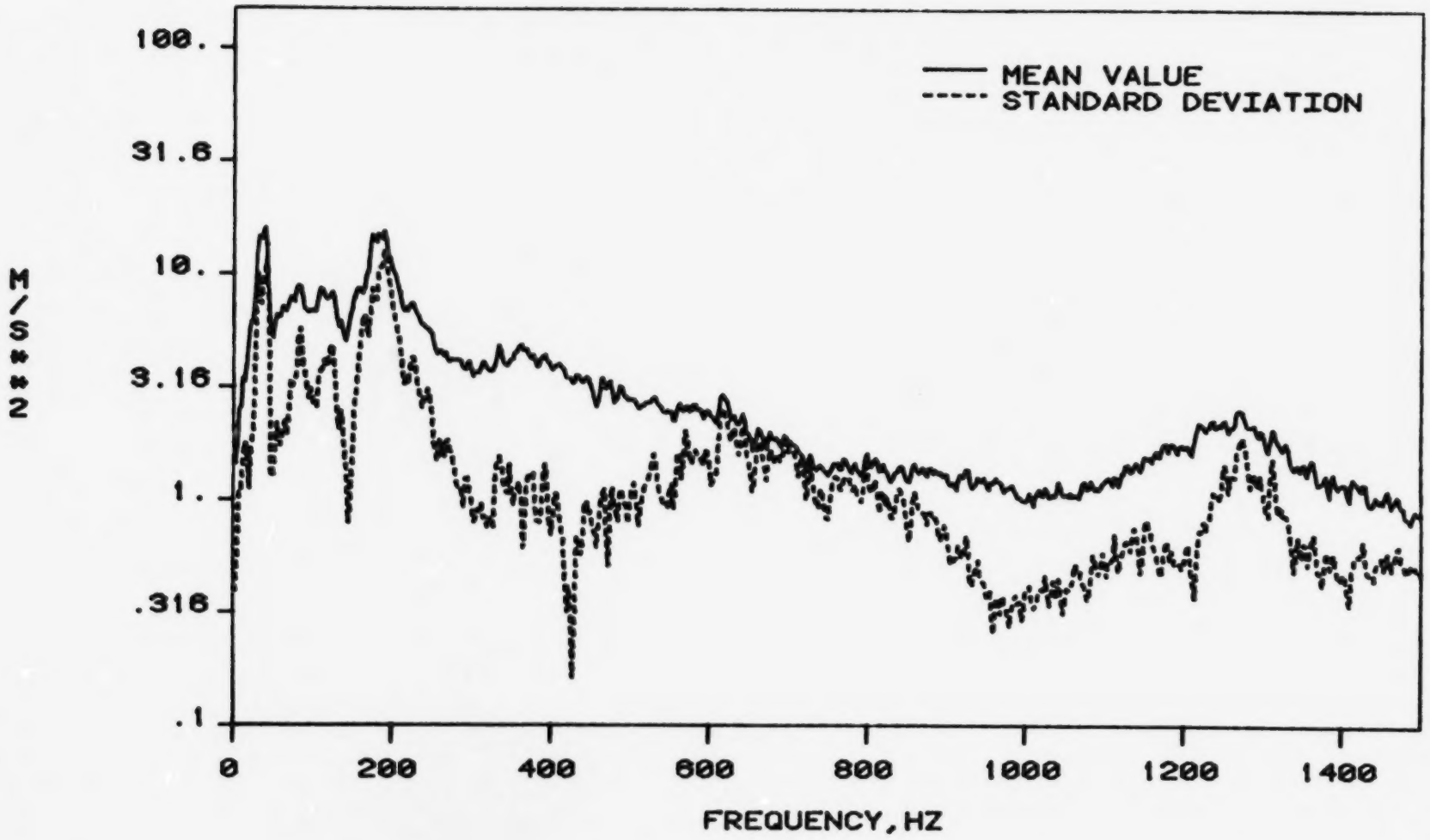


Figure 3.18c R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

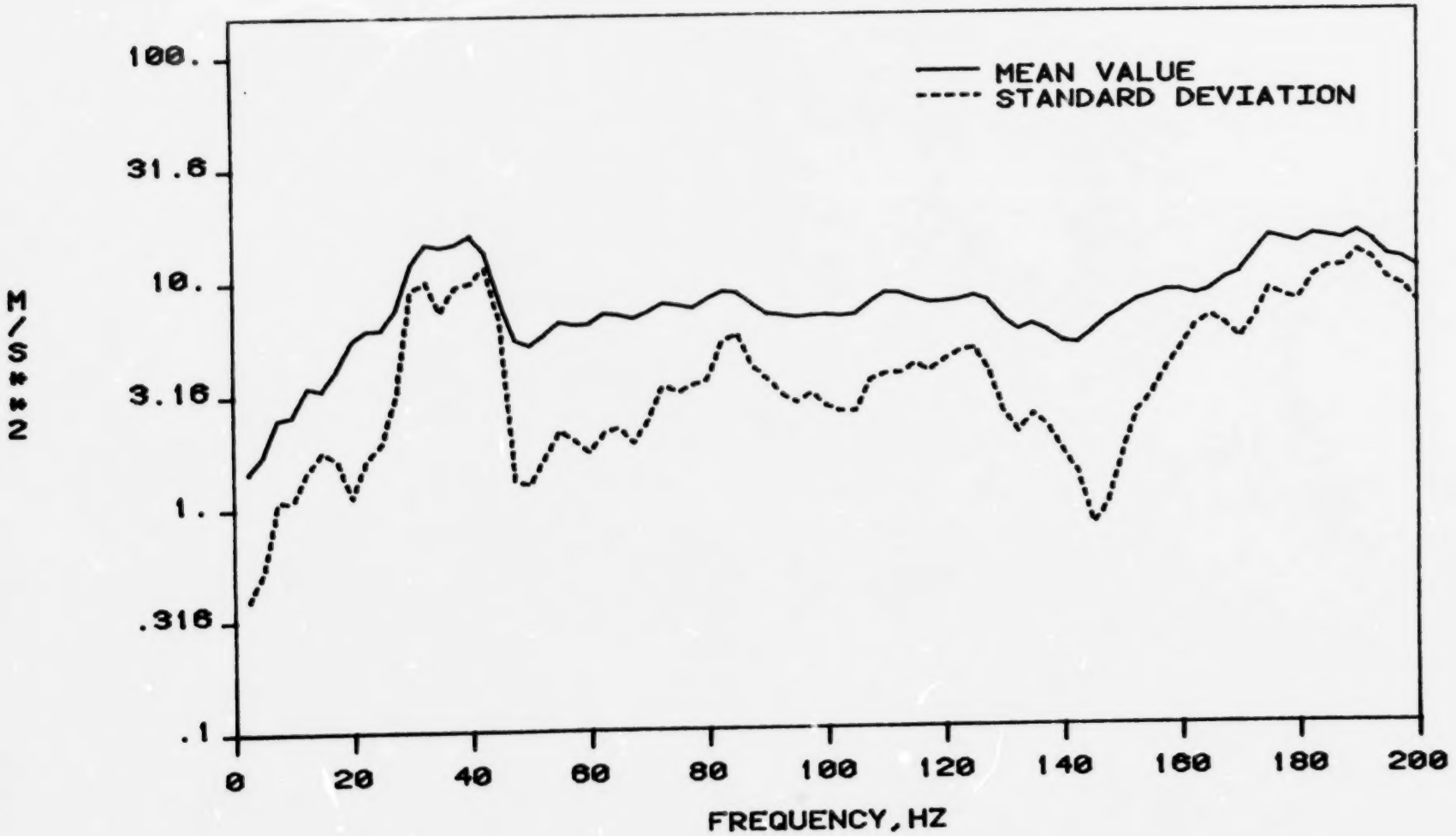


Figure 3.18d R.M.S. ACCELERATION SPECTRA RECORDED ON STOPER HOSE (3D,6S)

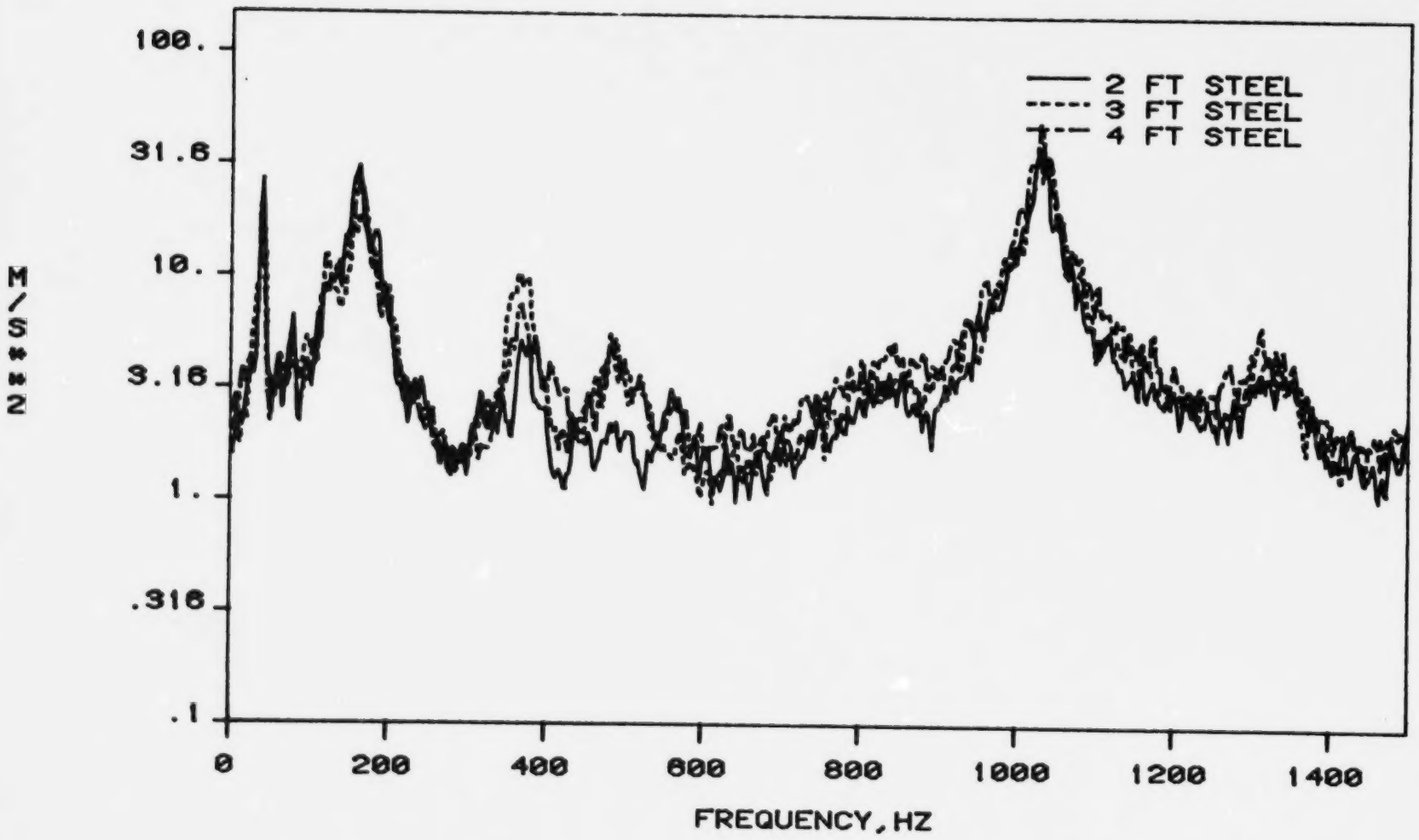


Figure 3.19a R.M.S. ACCELERATION SPECTRA FOR STOPER DRILL WITH DIFFERENT STEEL LENGTHS (1D,3S)

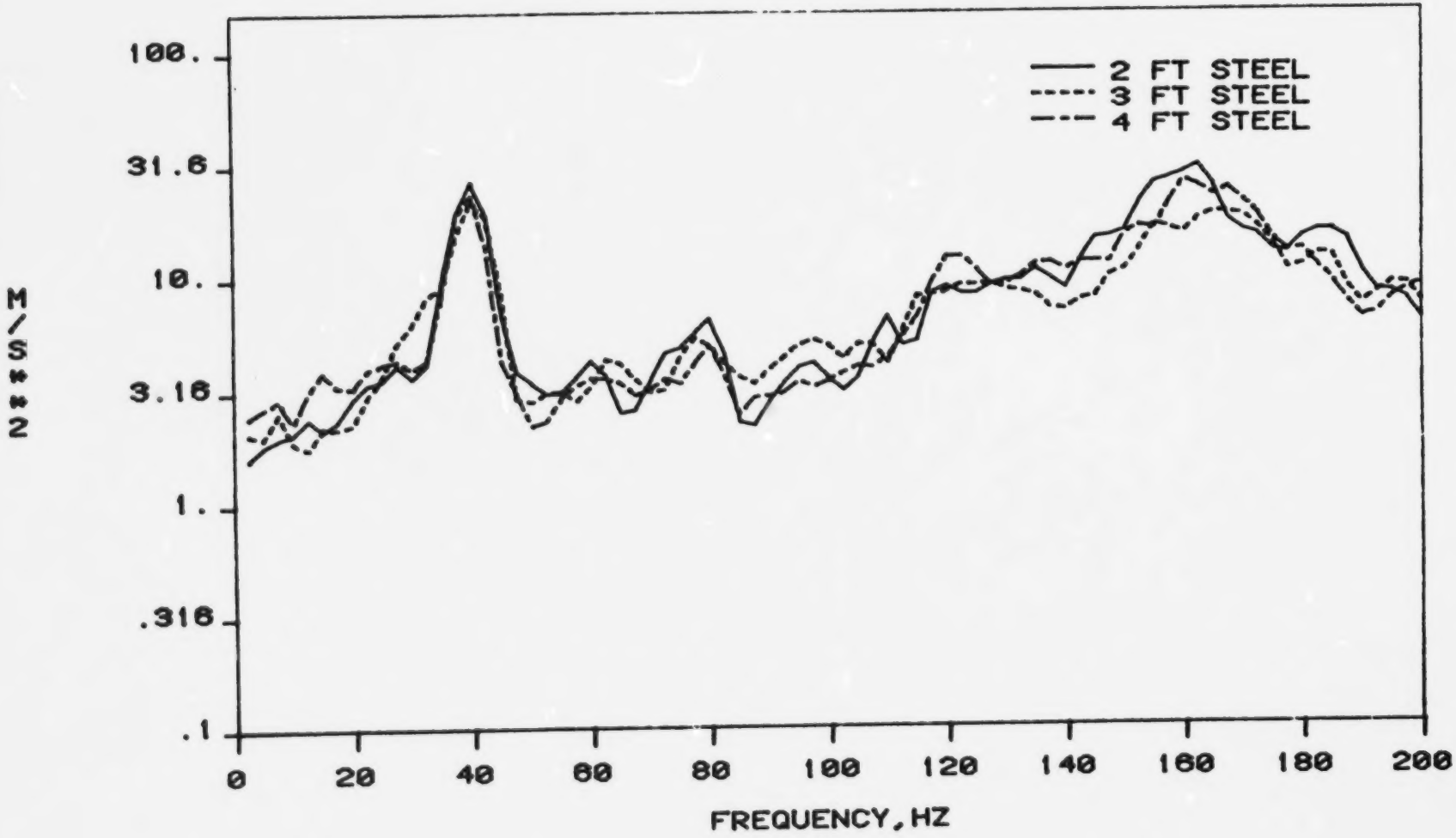


Figure 3.19b R.M.S. ACCELERATION SPECTRA FOR STOPER DRILL WITH DIFFERENT STEEL LENGTHS (1D,3S)

of tests conducted on a timber supported stoper of type A with different steel lengths.

Finally in Figures 3.20 a and b is presented a comparison of the three types of stoper that were tested at the Kimberley mine. The spectrum for drill A represents 5 samples taken from 2 drills; for drill B, 2 samples taken from 1 drill; and for drill D, 3 samples taken from 1 drill. All tests were conducted from a rock base. The results show different vibration spectra but similar vibration levels at low frequencies.

Drilling rates were monitored on 5 jack legs and 4 stopers. The average drilling times were found to be .62 minutes/foot for the jack leg and .55 minutes/foot for the stopers.

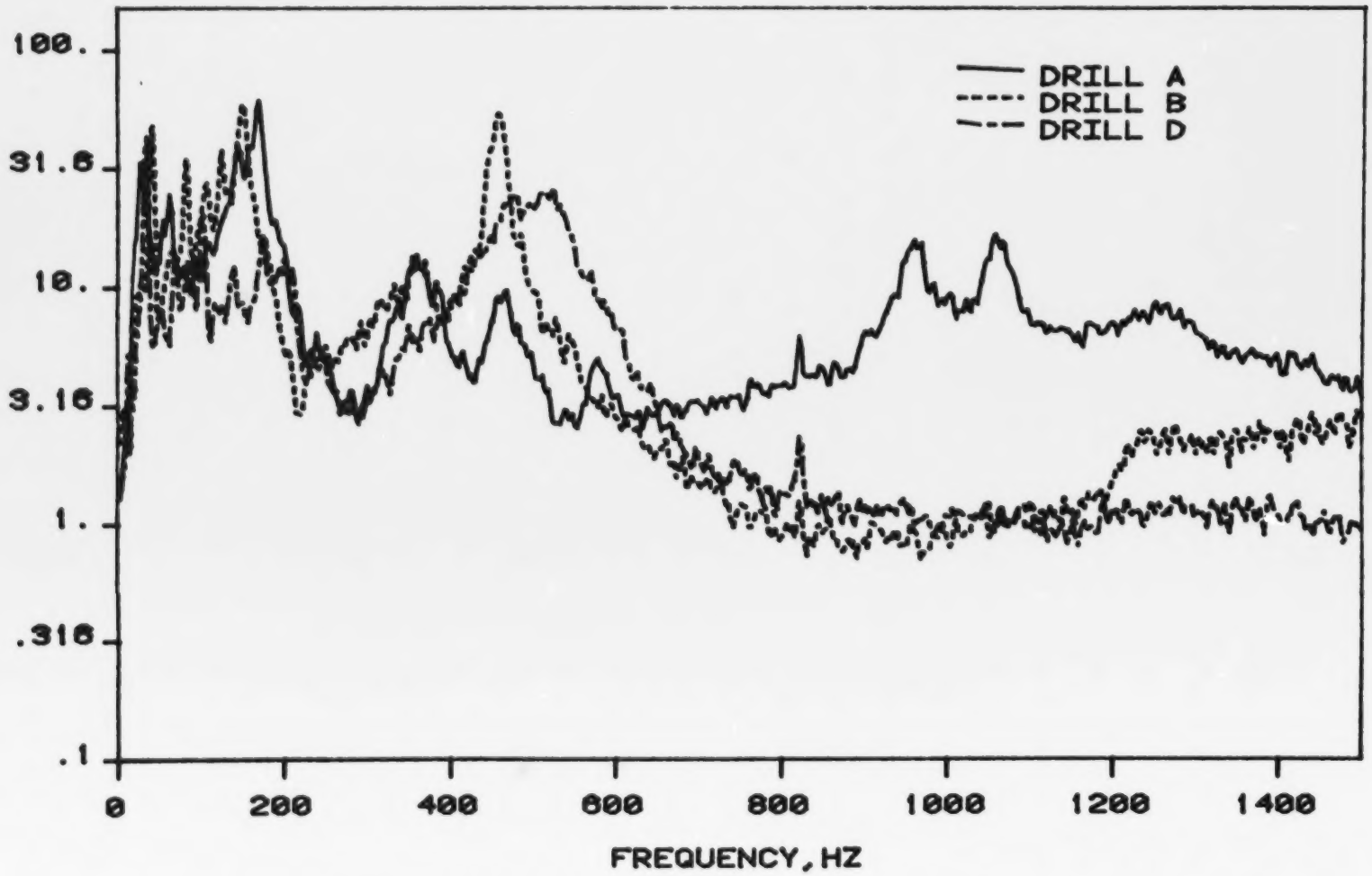


Figure 3.20a COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR DIFFERENT STOPER DRILLS (4D,10S)

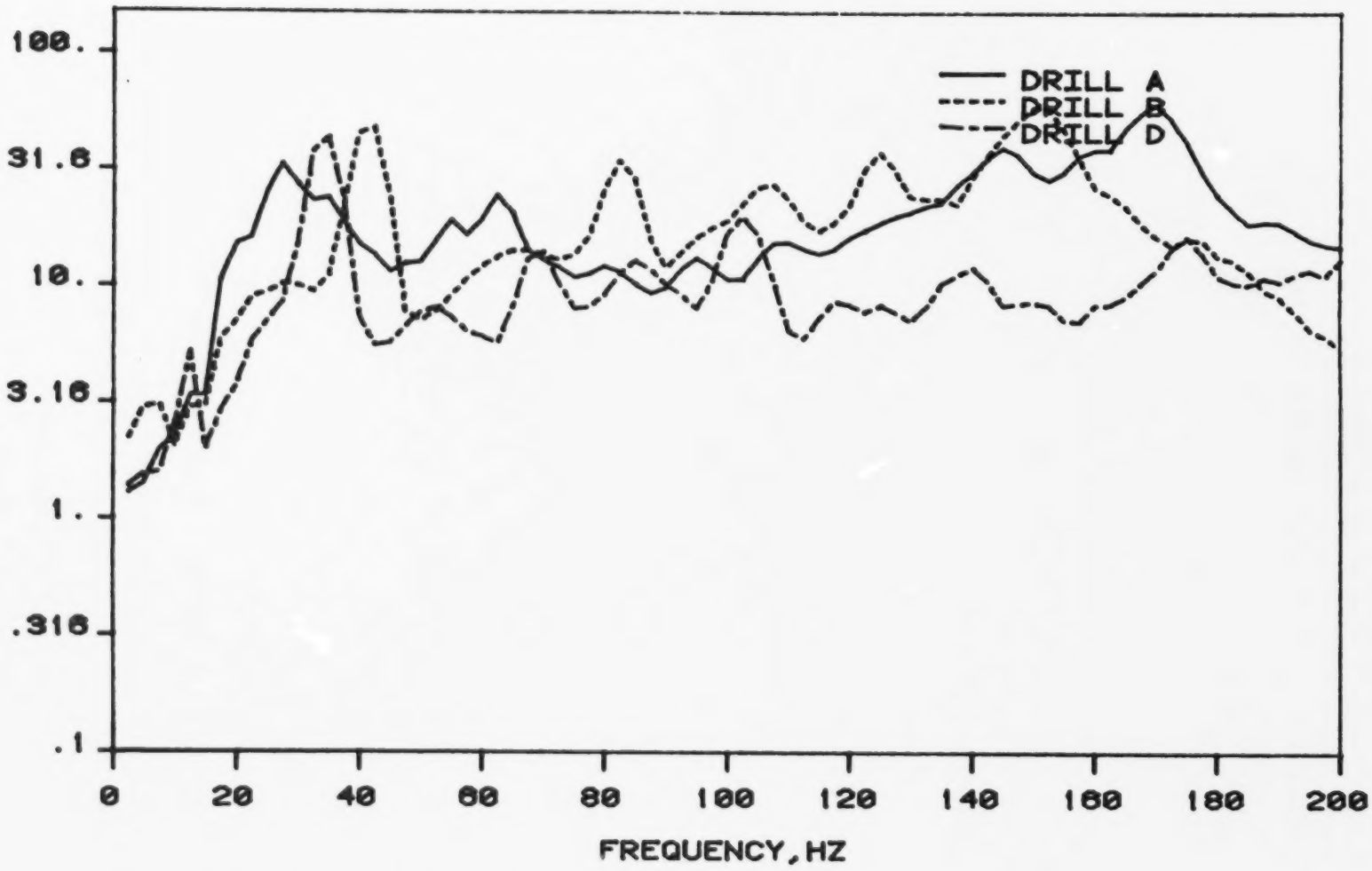


Figure 3.20b COMPARISON OF R.M.S. ACCELERATION SPECTRA FOR DIFFERENT STOPER DRILLS (4D,10S)

3.5 Comparison of Rock Drill Vibration Levels with Code Provisions

As is well recognized, the vibration levels associated with rock drills presently in use in Canadian mines are such that some miners suffer from vibration white finger disease (VWFD). At the present time there is insufficient information available on this problem to enable accurate predictions as to the level of vibration and exposure time that can be tolerated in order to avoid or reduce the incidence of VWFD. To aid in the assessment of the problem and to provide some tentative guide lines the International Standards Organization has issued a draft standard ISO DIS 5349 "Guide For the Measurement and the Assessment of Human Exposure to Vibration Transmitted to the Hand" which was most recently revised in September, 1982. To quote from this Standard:

> "This International Standard together with its annexes provides guidance for the evaluation of hand-transmitted vibration specified in terms of a frequency weighted vibration acceleration and daily exposure time. It does not define the limits of safe exposure.
>
> The guidance proposed in this International Standard is a consensus based upon data available from both practical experience and laboratory experimentation in the field of human response to hand-transmitted vibration. It cannot be taken to delineate completely safe exposure ranges in which vibration diseases cannot occur."

Further

> "General Considerations
>
> The severity of hand-transmitted vibration in working conditions is influenced by:
>
> (a) the frequency spectrum of vibration;
> (b) the magnitude of vibration;
> (c) the duration of exposure per working day and the total exposure time;

(d) the temporal exposure pattern and working method (i.e. length and frequency of work and rest spells; whether tool is laid aside or held idling during breaks in work, etc.); (e) magnitude and direction of forces applied by the operator through his hands to the tool or the workpiece;
(f) the posture of the hand, arm and body position during exposure (angles of wrist, elbow and shoulder joints);
(g) type and condition of vibrating machines, hand tool or workpiece;
(h) area and location of the parts of the hands which are exposed to vibration.

The severity of biological effects of hand-transmitted vibration in working conditions may be influenced by:
(a) the direction of the vibration transmitted to the hand;
(b) the method of working and the operator's skill;
(c) pre-disposing factors in the health of the individual.

The following factors may specifically affect the circulation changes caused by hand-arm vibration:
(a) climatic conditions;
(b) diseases which affect the circulation;
(c) agents affecting the peripheral circulation such as smoking, certain medicines or chemicals in the working environment;
(d) noise.

Although the importance of all factors listed with respect to the generation of vibration disorders is not yet known in sufficient detail, reporting of all factors is considered desirable in order to enable the collection of meaningful exposure histories. It is also important to report the measurement procedure and the statistical techniques used to evaluate the vibration data".

As may be recognized from these comments the factors affecting the development of VWFD may be varied. However this standard contains an annex: "Guidelines for the evaluation of hand-transmitted vibration exposure" which may be used to assess the potential of a given vibration level/dose time to cause VWFD. These guidelines are expressed in terms of a frequency weighted four hour energy equivalent acceleration which is related to time exposure before the onset of VWFD symptoms as shown in Figure

3.21, where the percentile figures refer to the percentage of exposed workers that are likely to suffer from the symptoms. The weighted acceleration a_{hw} is defined in terms of one third octave (or octave) band levels as

$$a_{hw} = \sqrt{\sum_{i=1}^{n} (K_i \, a_{hi})^2}$$

where

K_i is the weighting factor for the ith one third octave (octave) band.

n is the number of one third octave (octave) bands.

For one third octave bands K_i is defined by Table 3.1.

If the period of exposure does not correspond to 4 hours then the equivalent four hour weighted acceleration is determined from the formula

$$a_{hw(4)} = \left(\frac{T}{4} \right)^{1/2} a_{hw(T)}$$

where $a_{hw(4)}$ is the frequency weighted four hour energy equivalent acceleration, and $a_{hw(t)}$ is the frequency weighted acceleration measured, and T is the time in hours that the operator is exposed to the level $a_{hw(T)}$. It is the value of $a_{hw(4)}$ that is used in Figure 3.21 to determine the time exposure before the onset of symptoms.

In order to help assess the accuracy of the information contained in this standard, the data collected during this study was analysed as specified. The tape recorded data was frequency analysed using the Nicolet 660A on a range 0-2000 Hz which provided

Frequency (Hz)	Weighting Factor (K_i)
6.3	1.0
8.0	1.0
10.0	1.0
12.5	1.0
16	1.0
20	0.8
25	0.63
31.5	0.5
40	0.4
50	0.3
63	0.25
80	0.2
100	0.16
125	0.125
160	0.1
200	0.08
250	0.063
315	0.05
400	0.04
500	0.03
630	0.025
800	0.02
1000	0.016
1250	0.0125

Table 3.1 Values of K_i for conversion of one third octave band measurements to weighted measurements

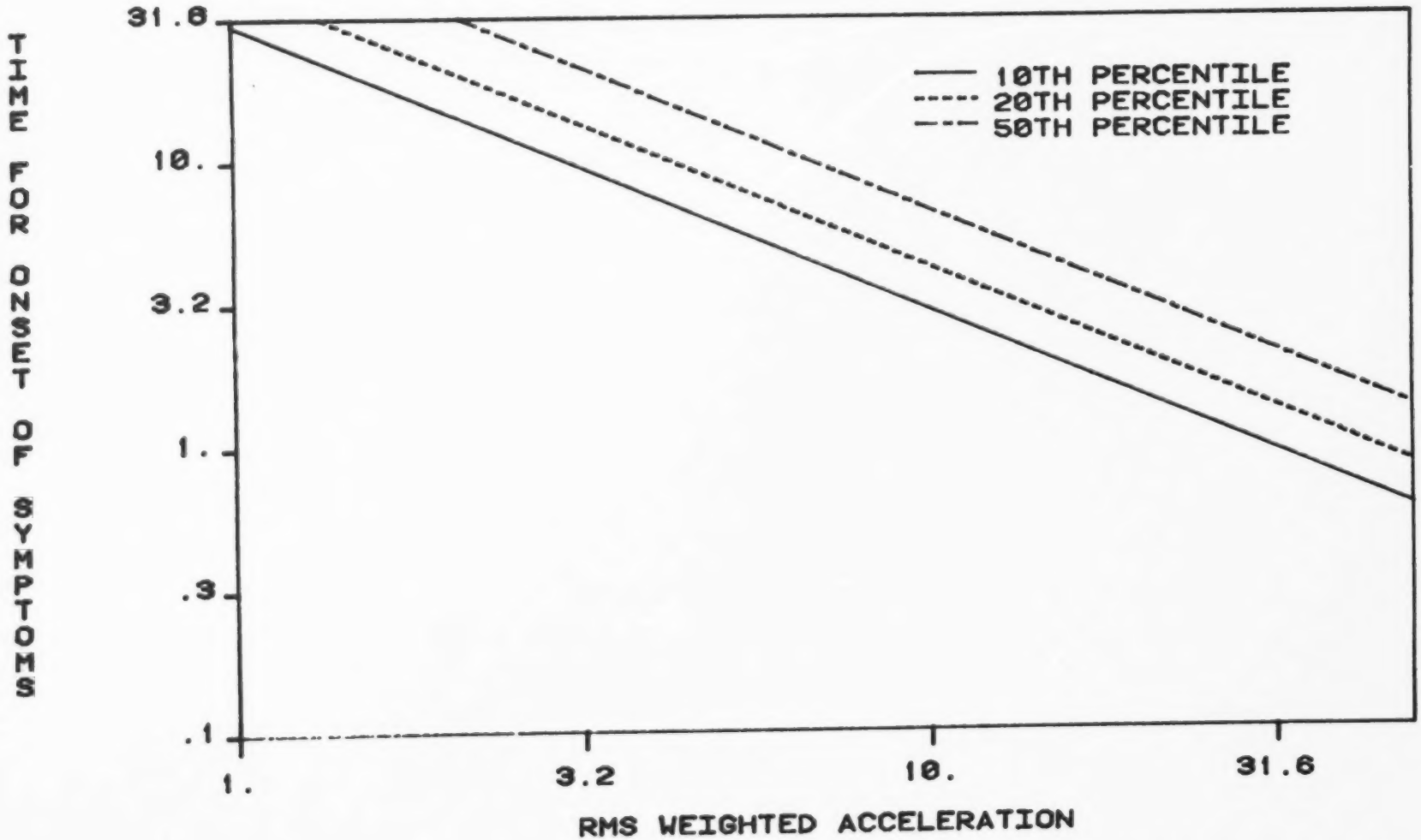


Figure 3.21 TIME IN YEARS FOR ONSET OF VWFD SYMPTOMS VERSUS WEIGHTED ACCELERATION LEVEL(m/s2)

a frequency reading every 2.5 Hz. This data in the range 5-1500 Hz was then weighted by a factor of 16 divided by the frequency in Hz for the range 16-1500 Hz, and by a factor 1 in the range 5 - 16 Hz. The weighted acceleration level was then calculated according to the standard. The program used for this computation (AHW) is given in the Appendix.

As reported in Section 3.3 the measurements were taken to ascertain the time exposure received by miners. These results indicated a maximum exposure of 1.5 hours per shift. Thus the equivalent four hour weighted acceleration is given by

$$a_{hw(4)} = \left(\frac{1.5}{4} \right)^{1/2} a_{hw} = .61\, a_{hw} \ .$$

Tables 3.2 and 3.3 present the results of the calculation of $a_{hw(4)}$ cross referenced to the graphs on which the spectra of the samples have been plotted.

Figure	Equivalent four hour weighted acceleration	Mean
3.1	19, 19, 20, 19	19
3.2	19, 19, 16	18
3.3	18, 29, 19, 27, 25, 19, 18, 20, 23, 30, 22, 27, 19, 19, 20, 19, 16, 17, 28, 24, 19, 19, 22, 19 19, 16, 17, 18, 17, 19, 19, 14, 14, 17, 17, 25 33, 11, 22, 19	20
3.4	24, 19, 24, 22, 19	22
3.5	18, 29, 19, 30, 16, 17, 19, 19, 16, 25, 11	20
3.6	27, 25, 20, 22, 28, 24, 22, 17, 18, 17, 33, 22	23
3.8	29, 24, 20, 17, 21, 19, 34	24
3.9	19	19
3.10	27, 19, 19, 27, 25, 26, 22, 16, 15, 21, 20, 17 22, 19, 20, 12, 18, 13, 19, 12, 14, 15, 16, 14 19, 19, 17, 14, 14, 32, 27, 21, 29, 21, 22, 24	20

Table 3.2 Weighted acceleration levels at Westmin Mine.

Figure	Equivalent four hour weighted acceleration	Mean
3.11	14, 14, 18, 20, 25, 16, 22, 27	19
3.12	14, 17, 17, 19, 20, 19, 19, 30, 30, 19, 19, 20	20
3.14(C) 3.14(D)	21 29	21 29
3.15	32, 30, 28, 13, 12, 12, 19, 17, 16,16	19
3.16	30, 33, 29, 34, 33	32
3.18	16, 14, 18, 11, 13, 17	15
3.20(A) 3.20(B) 3.20(C)	30, 33, 29, 34, 33 29, 24 21, 24, 20	32 26 22

Table 3.3 Weighted acceleration levels at Kimberley Mine.

As may be seen from the results quoted in Table 3.3 the jack legs of type A (Figure 3.11) and B (Figure 3.12) gave mean weighted acceleration levels of virtually the same value, 20 and 19 m/s^2 respectively. The rock supported stopers of type A (Figure 3.16) gave much higher levels 32 m/s^2 whereas the timber supported stopers (Figure 3.13) gave levels comparable with the jack leg drills. Stopers type B and D gave lower levels than A but there are insufficient samples to attach much weight to the result.

According to ISO DIS 5349 a weighted acceleration level of 20 m/s^2 i.e., that of the jack leg drill would give rise to the onset of VWFD after approximately 1-1/2 years in 10% of those exposed and after 3-1/2 years in 50% of the cases. The level of 32 m/s^2 measured for the rock supported stopers would lead to the onset of symptoms after approximately 1 year in 10% of the cases and after approximately 2-1/2 years in 50% of the cases. The corresponding times associated with hose vibration levels are 2 and 5 years.

The perception amongst miners is that jack leg drills are more likely to cause VWFD than stoper drills. This does not entirely correspond to the predictions quoted above although it must be remembered that when using a stoper the driller is more likely to release the handle during drilling than when using a jack leg drill.

3.5 Vibration Survey of the Refiner Mill and Compressor Room at the Westmin Mine

A vibration survey was conducted at the Westmin Mine of the vibration levels of various items of machinery and of various locations where mine personnel worked. The purpose of this work was to record the vibration level of areas where personnel are exposed to whole body vibration and also to record spectra for particular types of mining equipment.

With regard to whole body vibration ISO 2631 "Guide for the evaluation of human exposure to whole body vibration" makes recommendations concerning the effects of such vibration:

> " This International Standard defines and gives numerical values for limits of exposure for vibrations transmitted from solid surfaces to the human body in the frequency range 1 - 80 Hz. It may be applied, within the specified frequency range, to periodic vibrations and to random or non periodic vibrations with a distributed frequency spectrum."

The Standard defines three boundaries for considering the effect of the vibration in terms of a one third octave band analysis. These boundaries are (i) "Fatigue-decreased proficiency boundary", (ii) "Exposure limit", and (iii) "Reduced comfort boundary". In the present work only the "fatigue-decreased proficiency boundary" will be considered.

In order to obtain a one-third octave band analysis the tape recorded data was analysed by the Nicolet 660A on a frequency scale 0 - 200 Hz and these results were used to generate a one third

octave analysis using the program THIRD OCTAVE given in the Appendix.

The fatigue-decreased proficiency boundary should, according to ISO 2631 be used as the guiding limit where the primary concern is to maintain the working efficiency of a machine operator exposed to the vibration. The levels that have been used for comparison purposes in the report are based upon an exposure period of 8 hours.

Whole body vibration measurements were made on the floor at various points om the refiner area and in the compressor room. Readings were also taken on those items of equipment in these areas that give rise to the vibrations. The equipment measured in the refiner area consisted of a jaw crusher, a cone crusher, a rod mill and two ball mills. In Figure 3.22a is plotted, to a logarithmic frequency scale, the narrow band acceleration spectra obtained from the spectrum analyzer, the third octave level, and the ISO "fatigue-decreased proficiency boundary" for the vibration levels measured on the platform of the jaw crusher. The third octave bands with centre frequencies of 10 and 12.5 Hz both slightly exceed the recommended levels. The interpretation of the boundary is that if any third octave band exceeds the boundary level then the vibration level is such that those exposed to such levels for a continuous 8 hour period are likely to suffer from a reduced level of efficiency. In Figure 3.22b the platform around the jaw crusher is shown as well as the location of the accelerometer.

Readings were taken on the top of the cone crusher and on its concrete base (see Figure 3.23a) and these results are presented in Figure 3.23b and c respectively. The readings were taken at

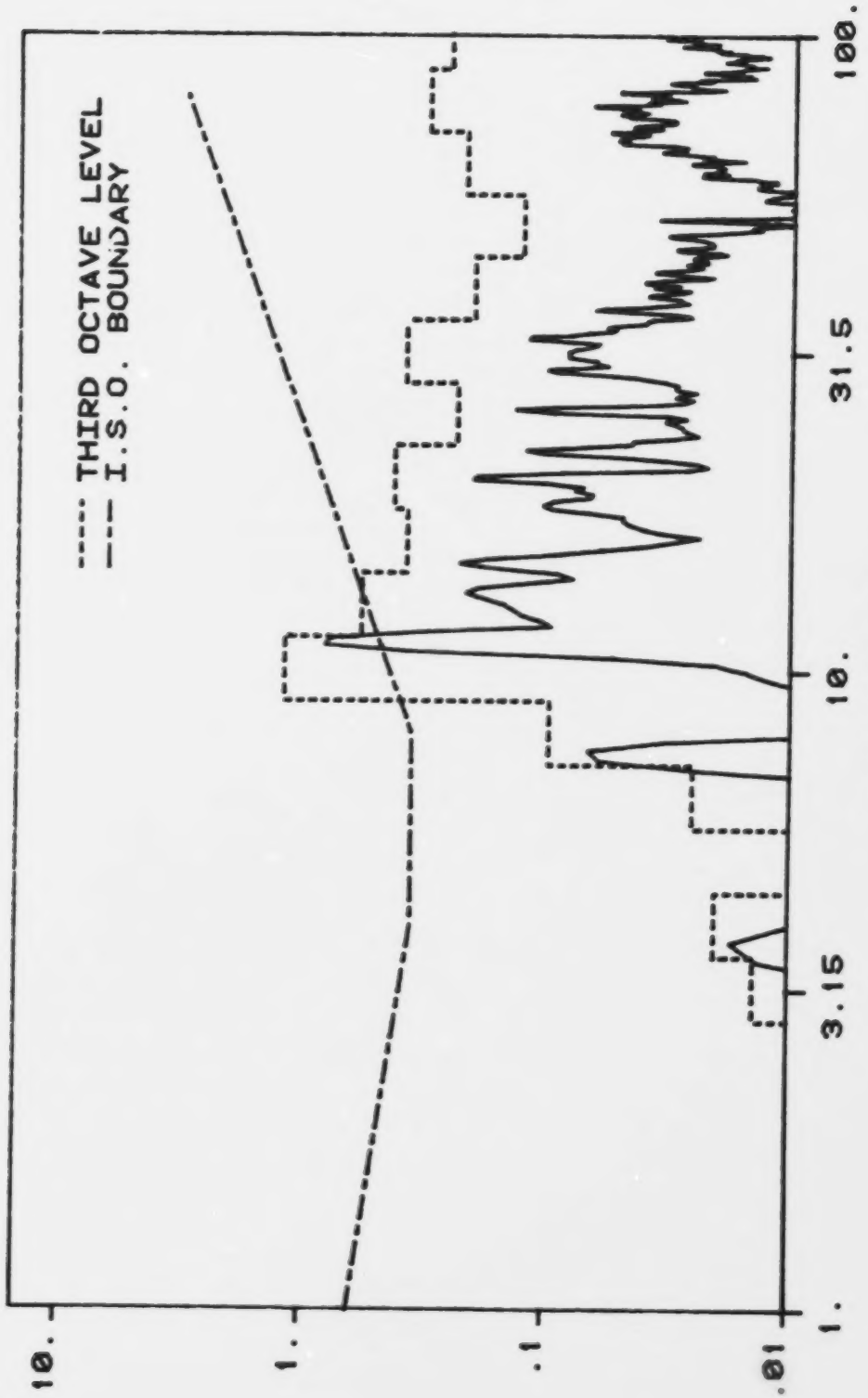
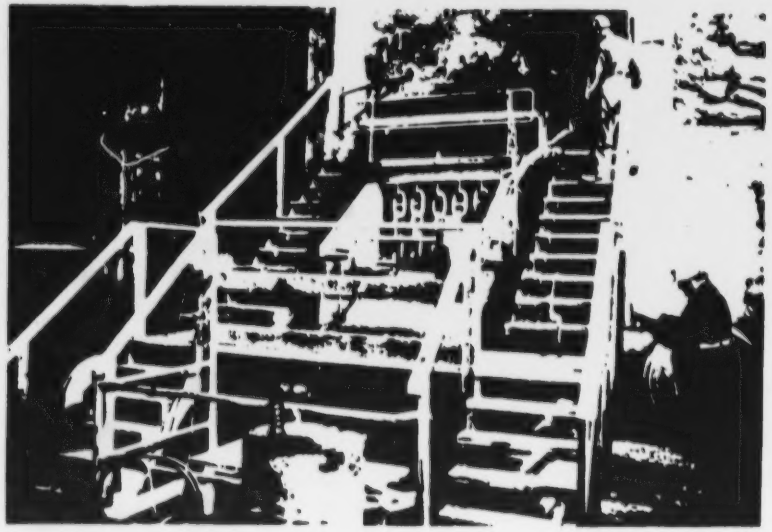


Figure 3.22a R.M.S. ACCELERATION SPECTRA FOR PLATFORM AROUND JAW CRUSHER



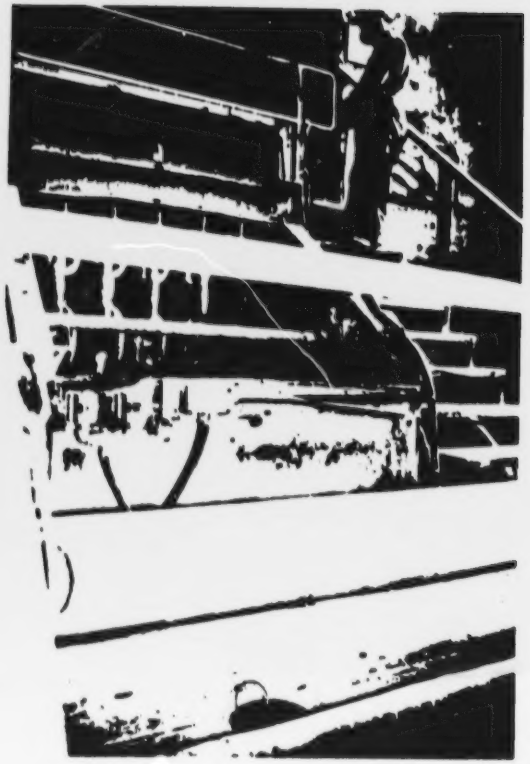
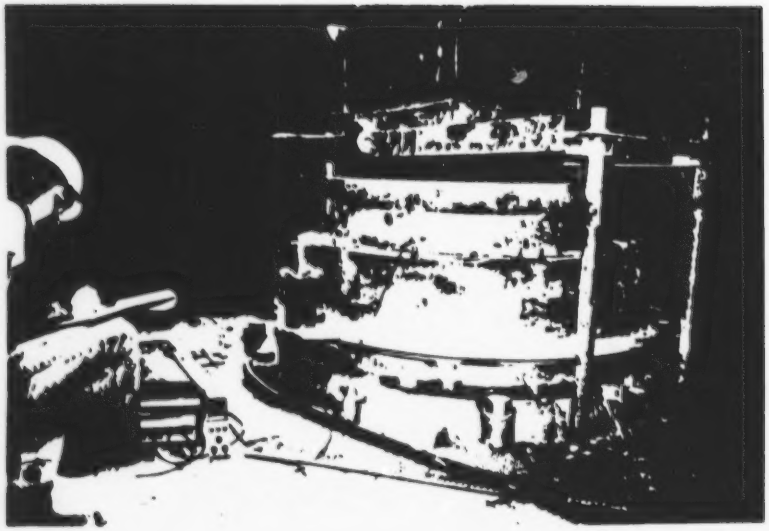


Figure 3.22b JAW CRUSHER PLATFORM



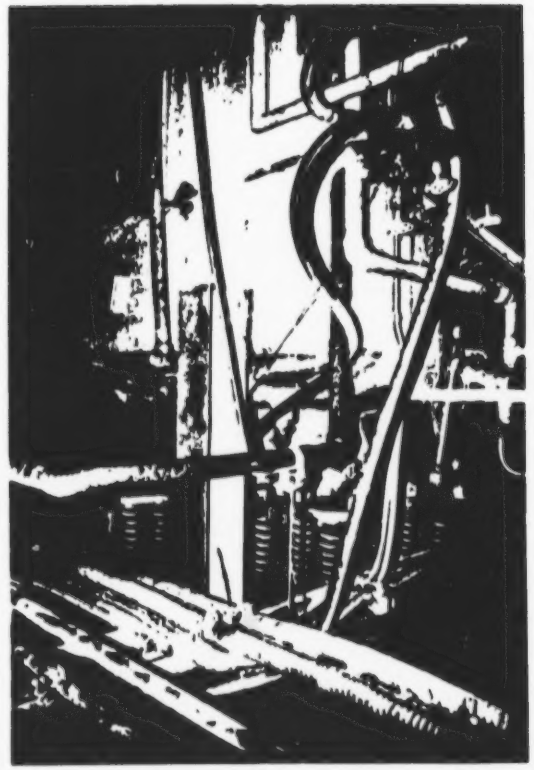


Figure 3.23a LOCATION OF READINGS ON CONE CRUSHER AND ITS BASE

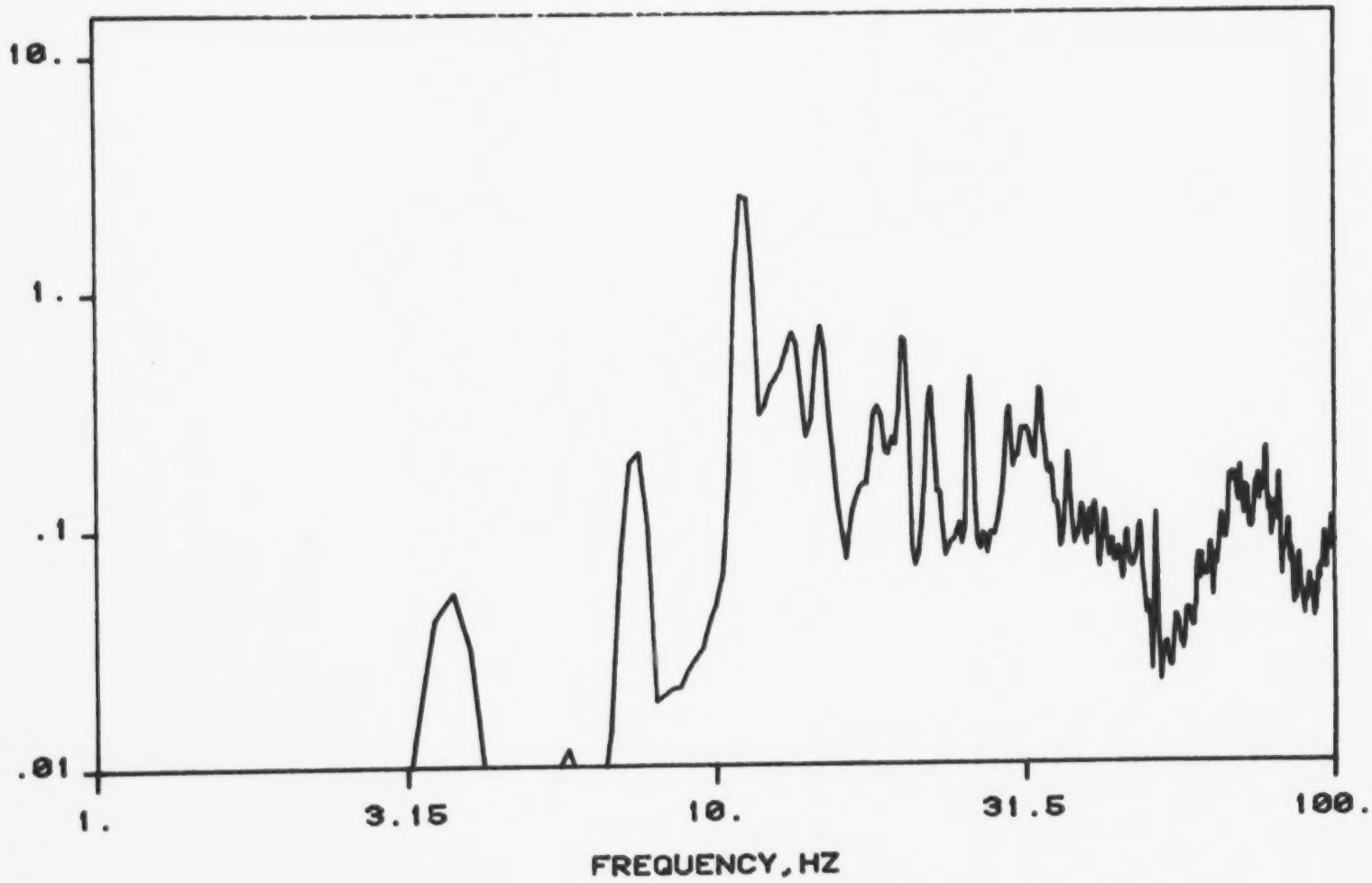


Figure 3.23b R.M.S. ACCELERATION SPECTRUM ON CONE CRUSHER

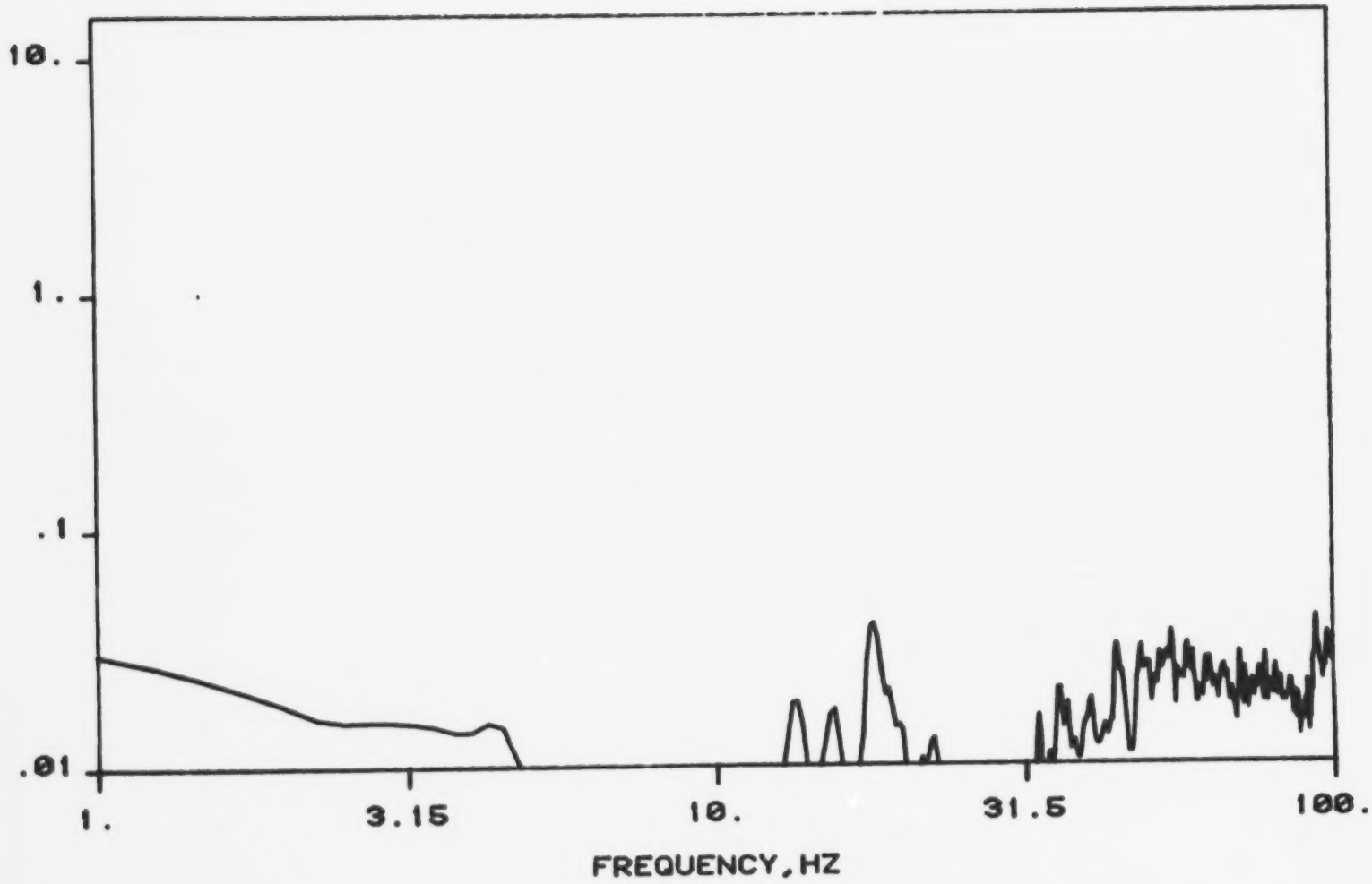


Figure 3.23c R.M.S. ACCELERATION SPECTRUM ON CONE CRUSHER

different times but in both cases with the crusher full. As can be noted the isolation system is effective in reducing the vibration levels.

Figure 3.24a presents the results taken on the floor near the rod mill, in Figure 3.24b the results taken on the bearing housing of the rod mill are given and in Figure 3.24c the location of these tests is shown. The levels recorded were quite low. In Figures 3.25 a-c equivalent results are given in the location of one of the ball mills, again the vibration levels are low.

Higher vibration levels were found on the slusher-platform loading area, and these results are presented in Figures 3.26a,b. Although the "fatigue-decrease proficiency boundary" has been slightly exceeded, in this case the operator is not in fact subjected to continuous vibration exposure.

Low levels of vibration were also recorded in zinc flotation area and these are recorded in Figure 3.27a.

In the compressor room readings were taken on the base of a diesel engine, on the isolated concrete foundation and on the floor adjacent to the isolated foundation. Figure 3.28a shows the location of these measurements and the results are presented in Figure 3.28 b-d. The engine had an operating speed of 1200 RPM (20Hz) and the harmonics of this frequency are clearly evident in the results recorded. The isolation system employed is effective in reducing the vibration levels.

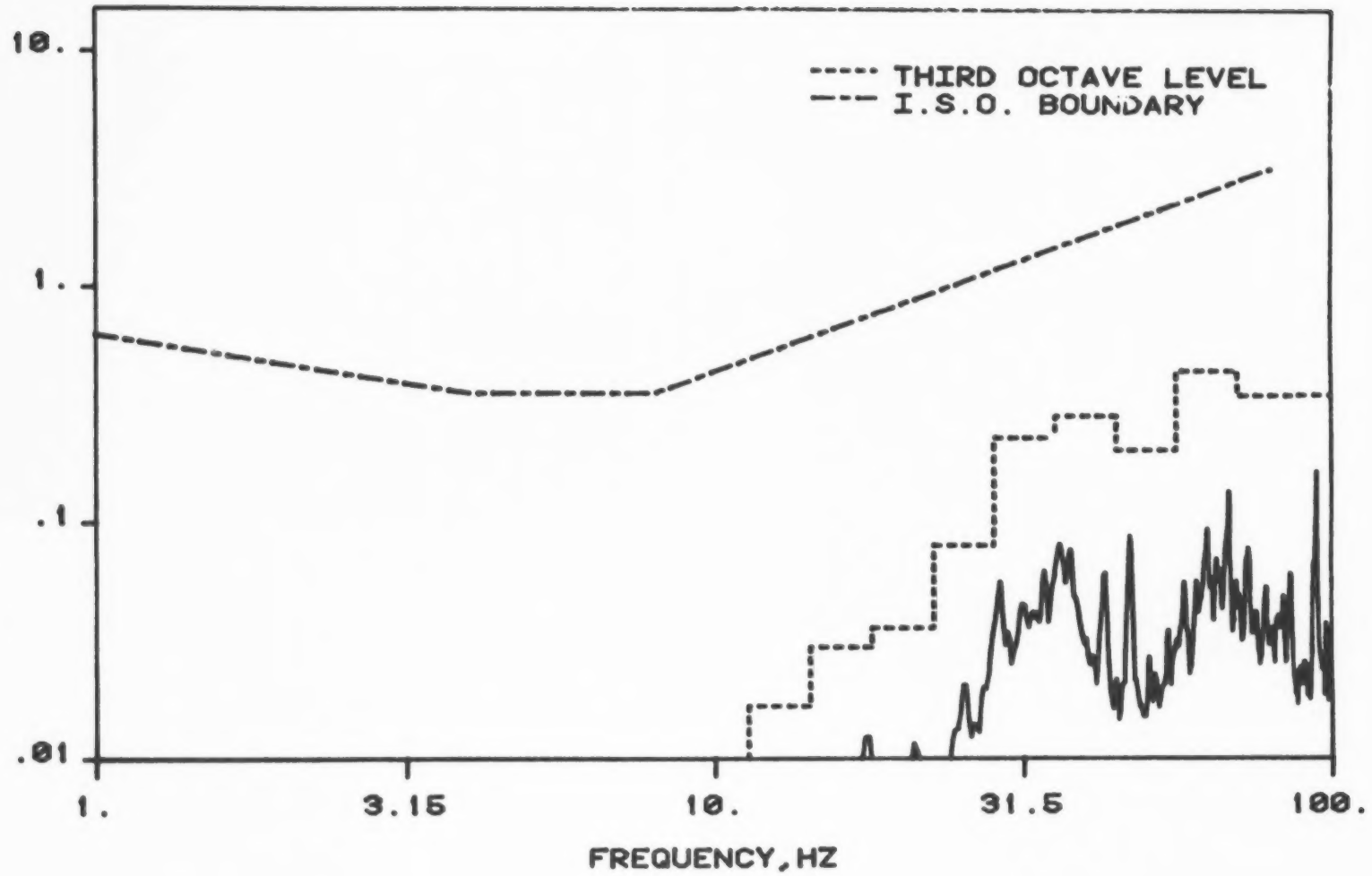


Figure 3.24a R.M.S. ACCELERATION SPECTRA FOR FLOOR ADJACENT TO ROD MILL

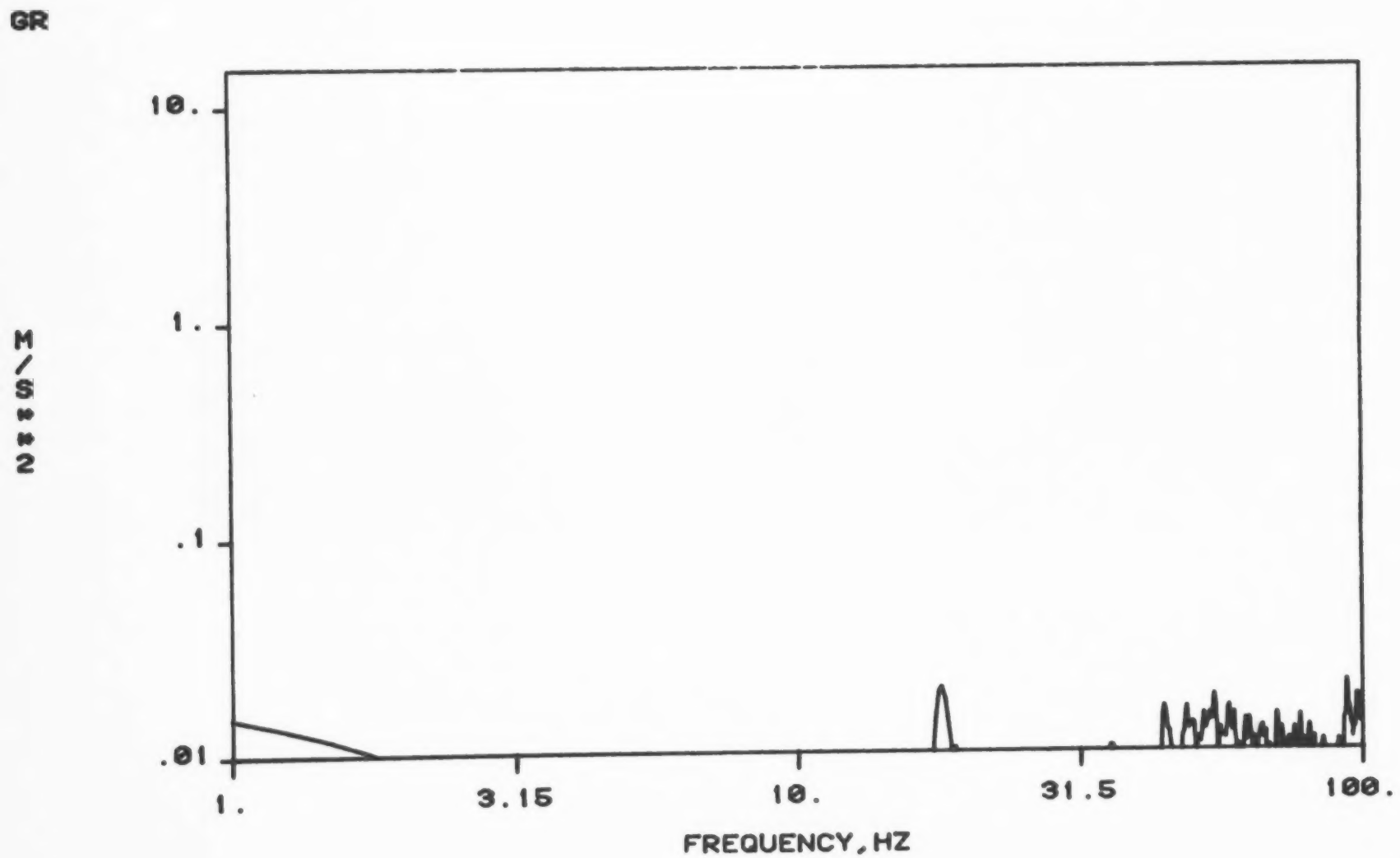


Figure 3.24b R.M.S. ACCELERATION SPECTRA ON BEARING HOUSING OF ROD MILL

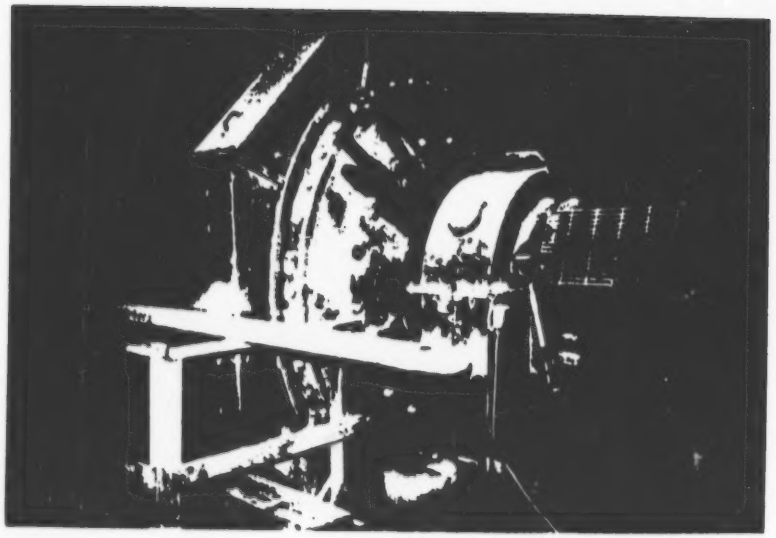


Figure 3.24c LOCATION OF ACCELEROMETER FOR ROD MILL TESTS

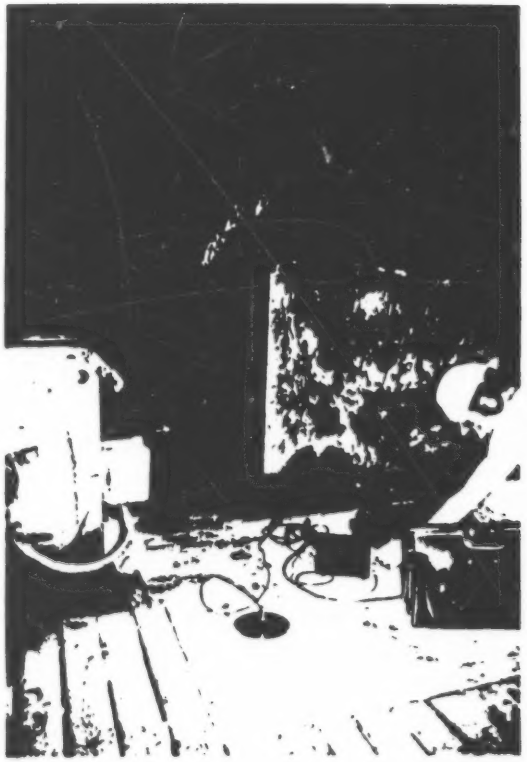


Figure 3.25a LOCATION OF READINGS FOR BALL MILL

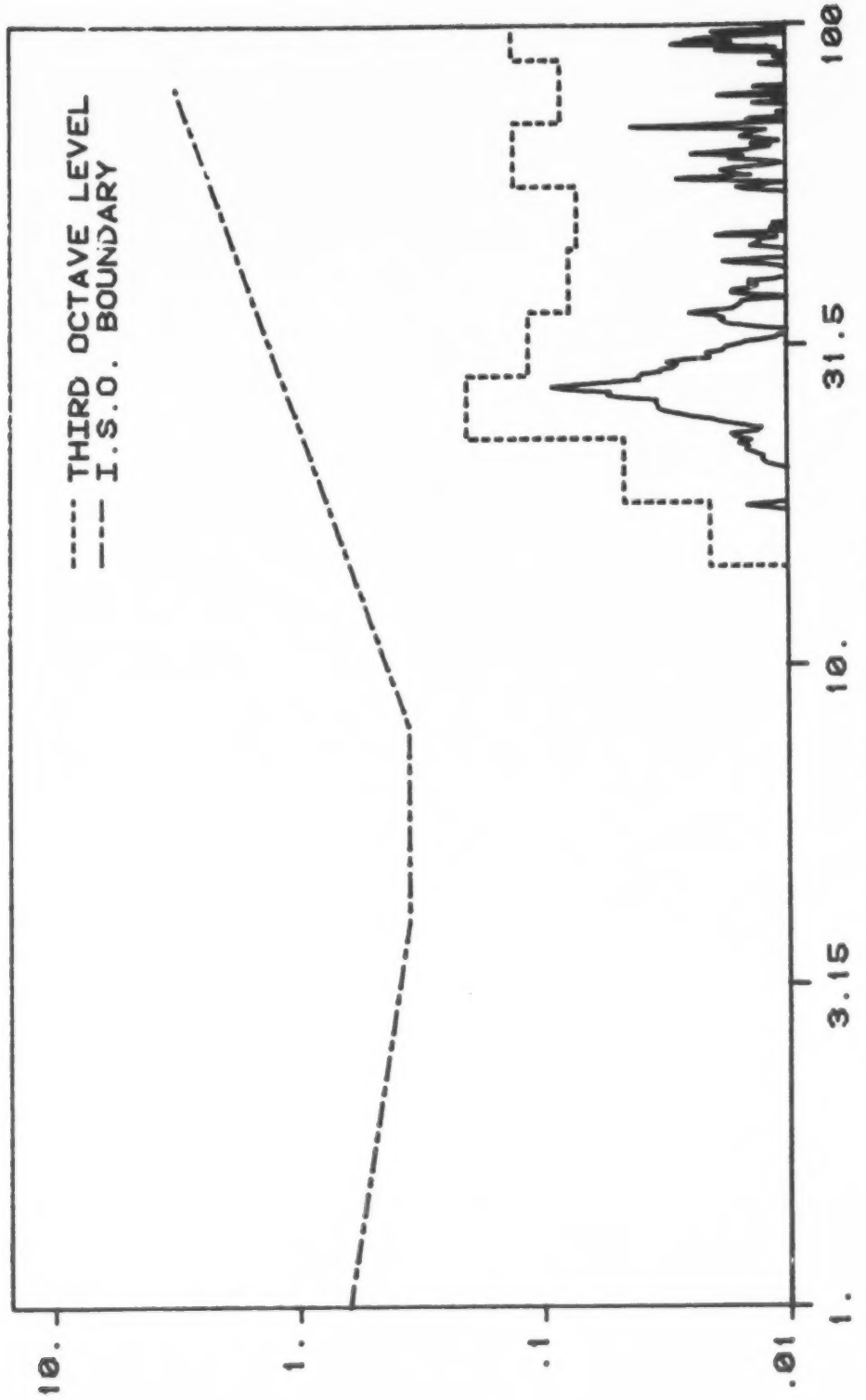


Figure 3.25b R.M.S. ACCELERATION SPECTRA FOR FLOOR NEAR BALL MILL

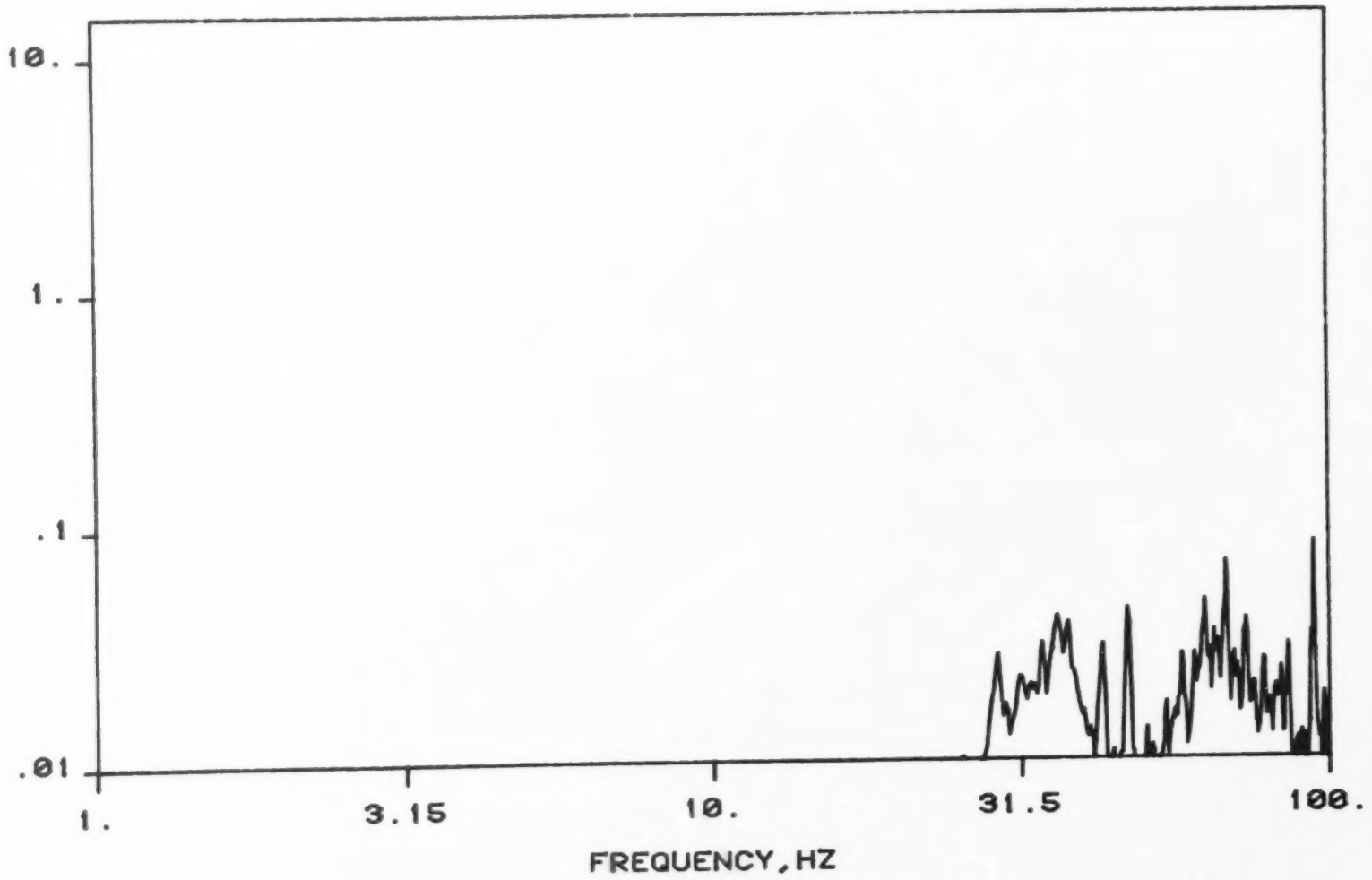


FIGURE 3.25c R.M.S. ACCELERATION SPECTRA FOR BALL MILL

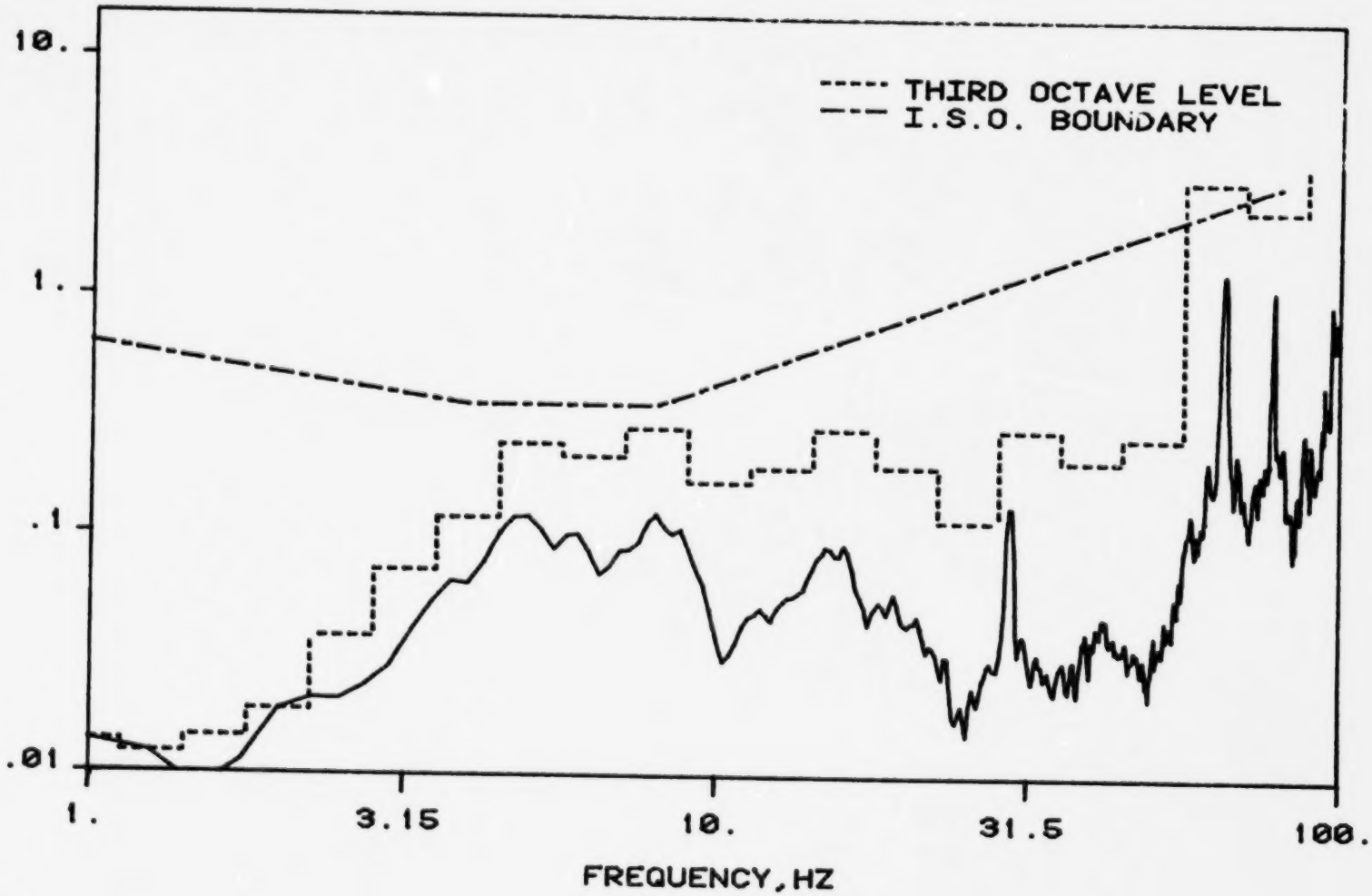


Figure 3.26a R.M.S. ACCELERATION SPECTRA FOR SLUSHER-PLATFORM

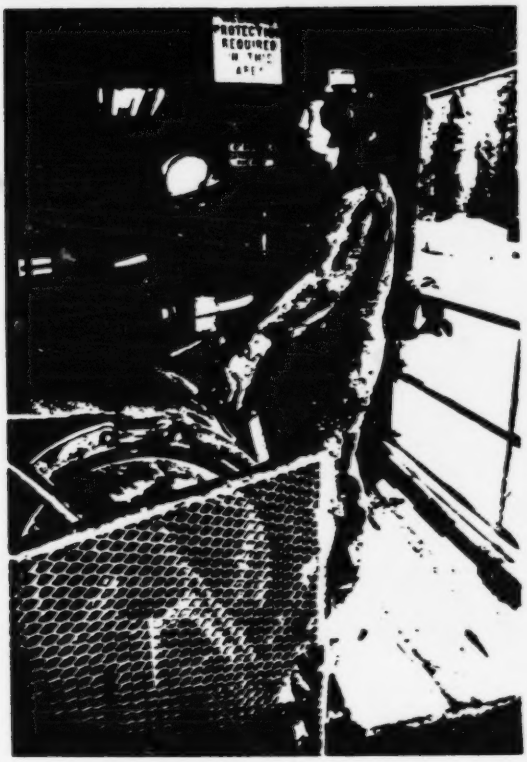


Figure 3.26b SLUSHER PLATFORM

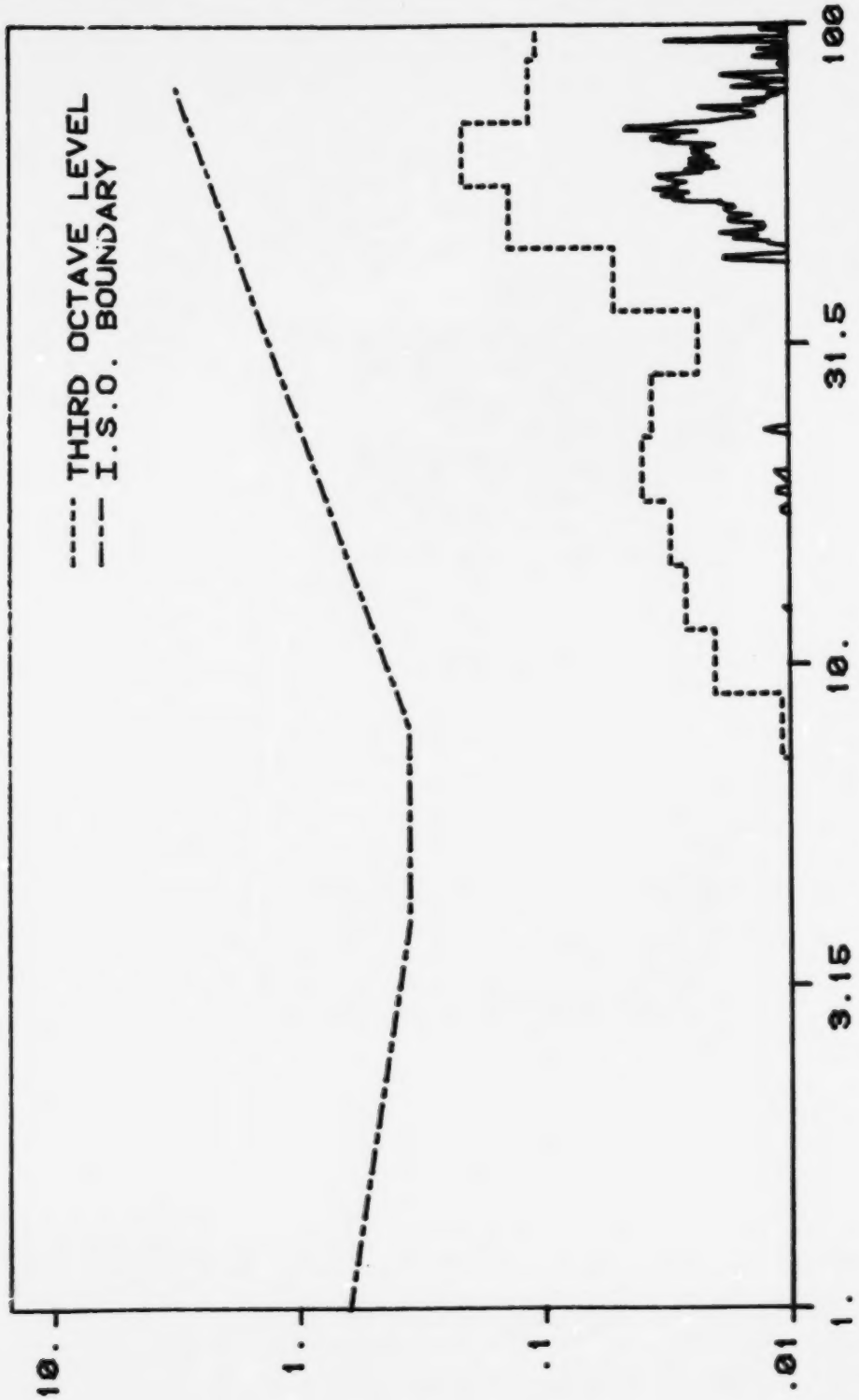


Figure 3.27a R.M.S. ACCELERATION SPECTRA ON FLOOR IN ZINC FLOTATION AREA

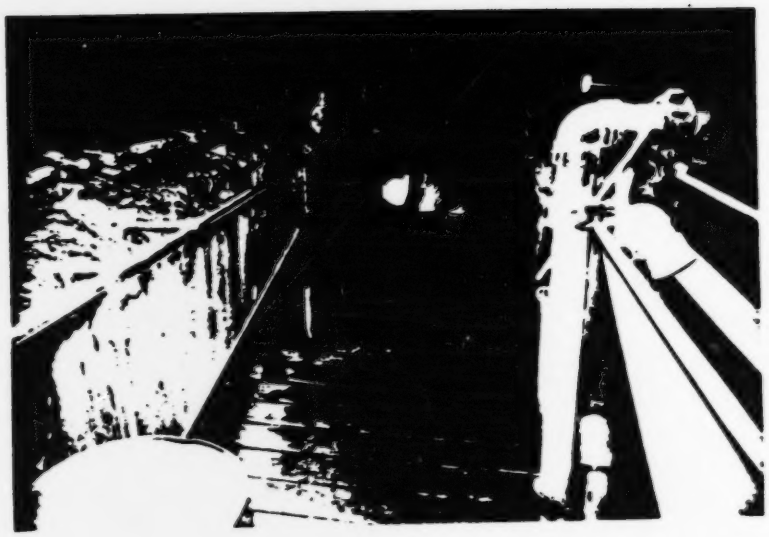


Figure 3.27b ZINC FLOTATION AREA

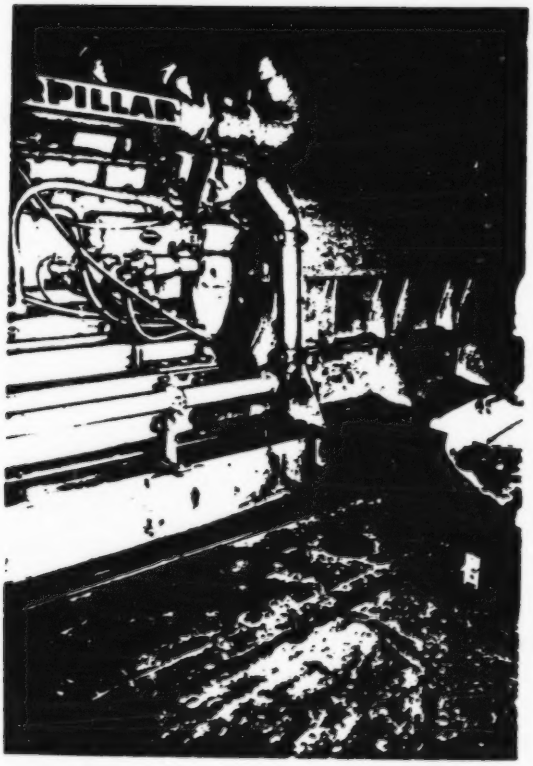


Figure 3.28a DIESEL ENGINE IN COMPRESSOR ROOM

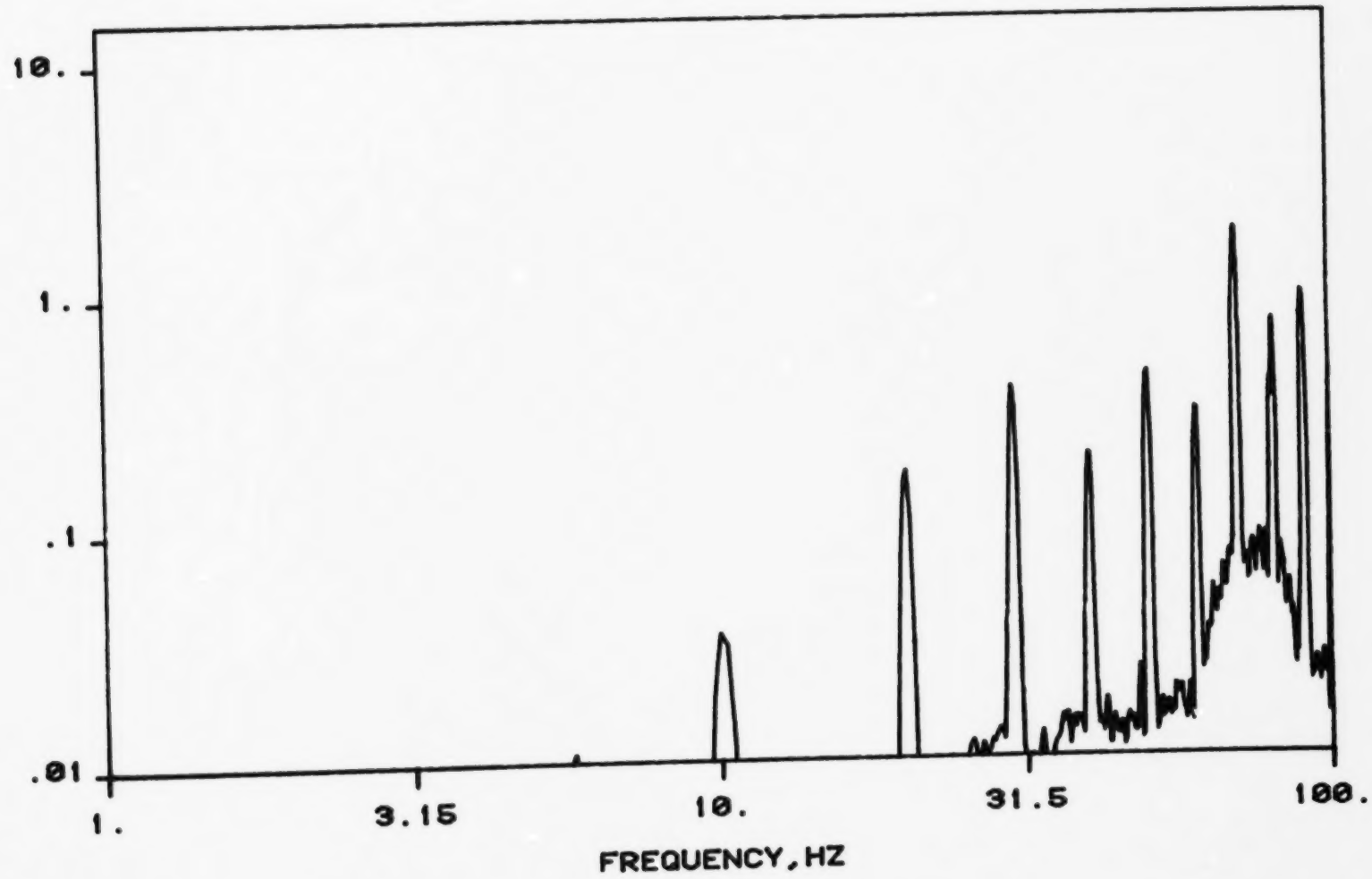


Figure 3.28b R.M.S. ACCELERATION SPECTRA ON DIESEL ENGINE BASE

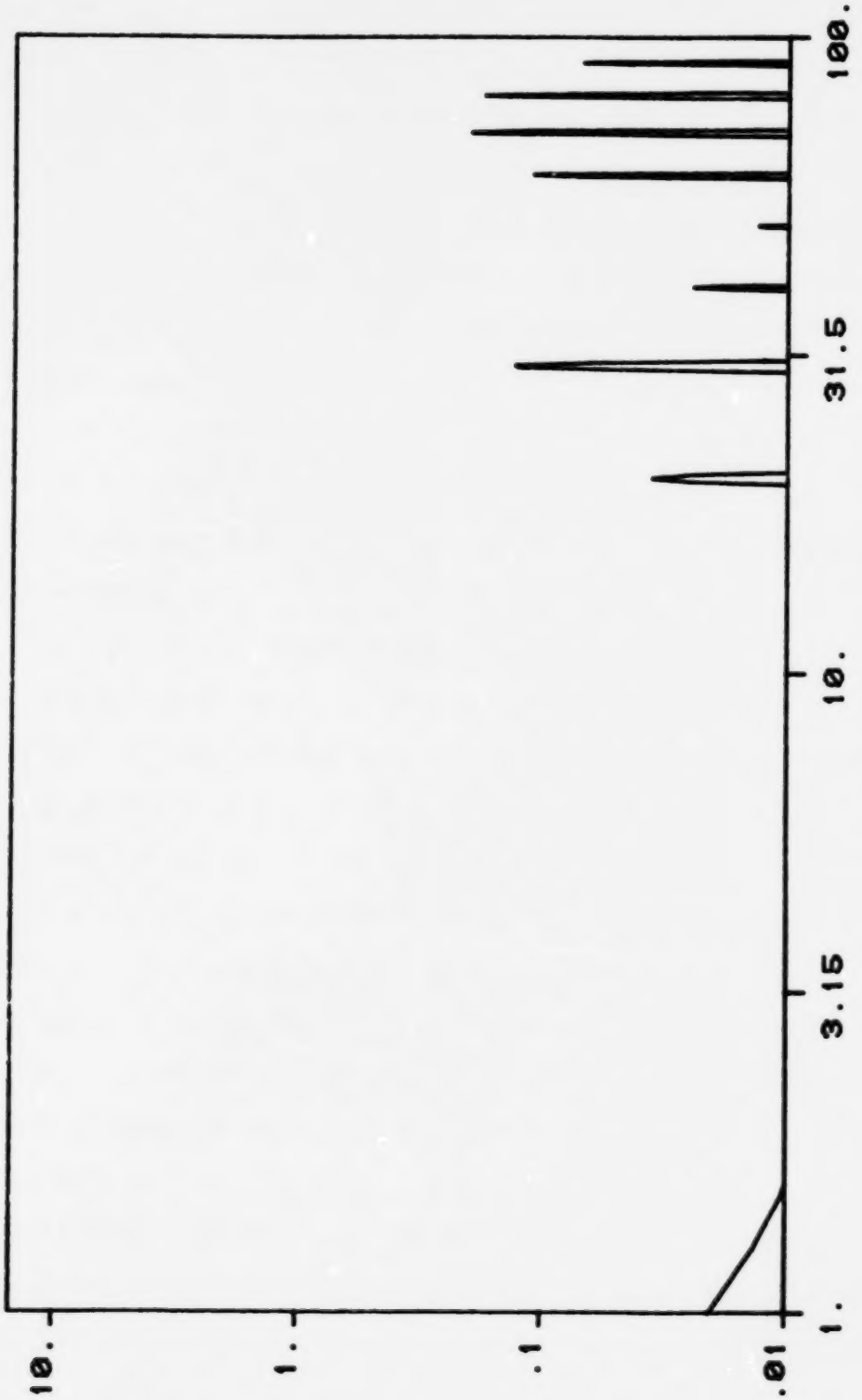


Figure 3.28c R.M.S. ACCELERATION SPECTRA ON ISOLATED FOUNDATION

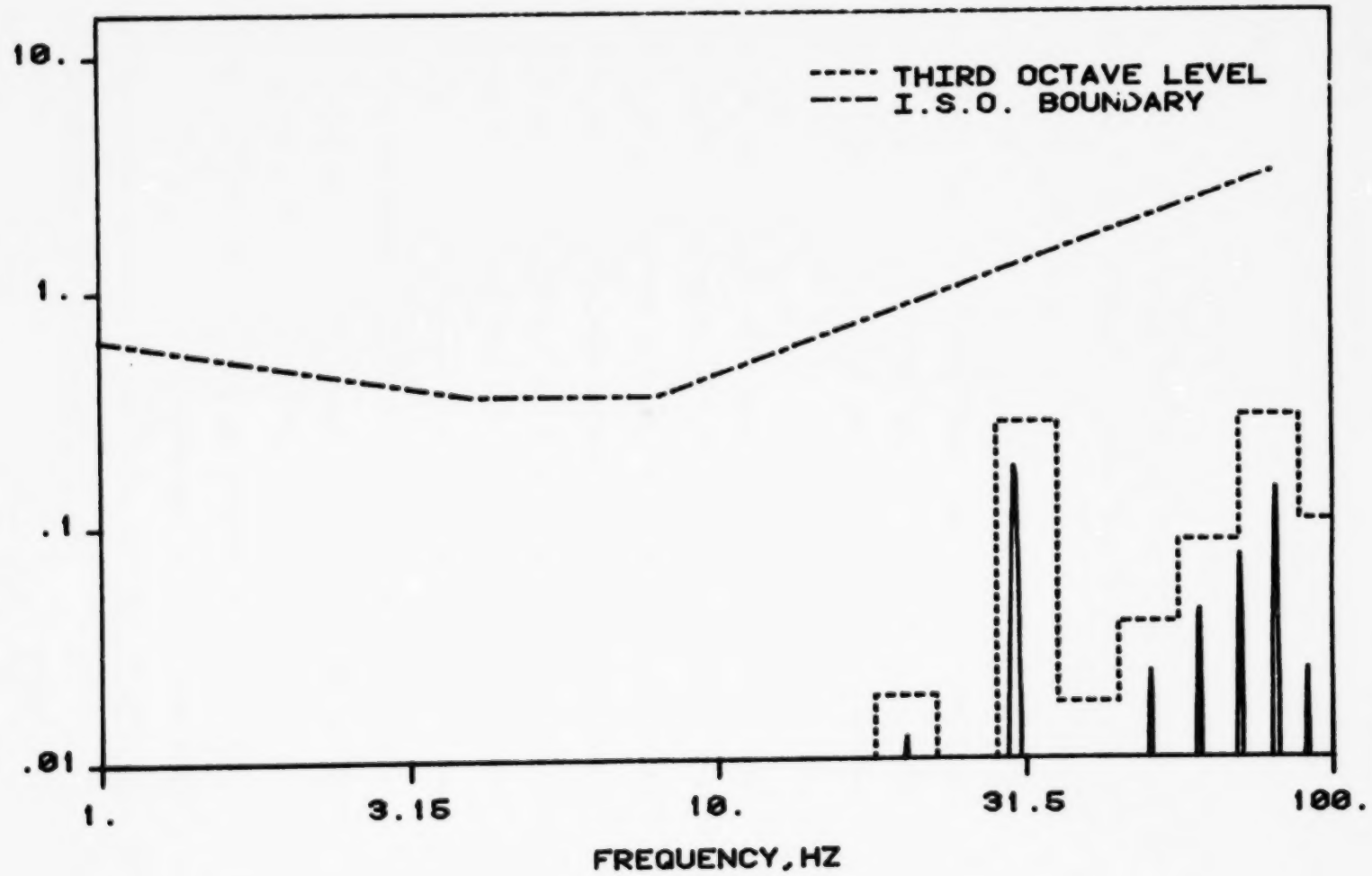


Figure 3.28d R.M.S. ACCELERATION SPECTRA ON CONCRETE FLOOR

3.7 Conclusions

Tests have been conducted on jack leg and stoper drills that provide much needed data on the vibration characteristics of these drills, and the influence of various operating parameters. Results taken for a single drill have been found to be highly repeatable and averaged spectra for both jack leg and stoper drills have demonstrated the existence of a well defined vibration spectrum for each drill. The effect of steel length and air pressure variations was not found to have a measurable effect on the vibration levels produced. The support condition, either timber or rock, was noted to have a marked effect on the vibration level of stoper drills.

The field results obtained have been analysed according to ISO DIS 5349 and the time taken for the onset of VWFD symptoms has been predicted. All the jack leg results obtained had approximately the same weighted acceleration level of close to 20 m/s^2 (for a 1.5 hours exposure time) which was the same as the average of all the stopers tested at the Westmin mine, whereas average levels of 32 m/s^2 were recorded at the Kimberly mine for some stopers. These results indicate that that the stoper produces vibrations that are likely to be more harmful than the jack leg. However as a stoper miner often holds the hose (which had a weighted acceleration level of 15 m/s^2) he may in fact take more time to develop VWFD symptoms.

Whole body vibration readings were recorded in the refiner and compressor room areas and locations were found where the vibration levels would, according to ISO 2631, give rise to reduced worker proficiency for an exposure period of eight hours.

4. LABORATORY TESTS

4.1 Introduction

In this portion of the study laboratory tests were conducted at the University of British Columbia to investigate the possibility of reducing vibration levels by of rock drills using relatively simple procedures that did not entail redesign of the drill firing mechanism.

Tests were conducted on a jack leg drill. The test configurations used were designed to check the effectiveness of the concept under evaluation and were not intended to be prototype developments.

Vibration measurements were taken by recording acceleration levels from accelerometers (Bruel and Kjaer 4332, 4375, 4370, 4336, 4344) attached to the drill via a mechanical filter (Bruel and Kjaer UA 0559) which was required in order to prevent excessive shock levels from damaging the accelerometer. The output from the accelerometer was amplified (Bruel and Kjaer 2635 and Kistler 504A) and stored on a FM tape recorder (Bruel and Kjaer 7003). A reference signal was provided by an accelerometer calibrator (Bruel and Kjaer 4291). Interpretation and analysis of the data was accomplished using a Nicolet 660A spectrum analyzer.

The experimental work conducted was designed to

(i) investigate the possibility of reducing the vibrations levels transmitted to the handle of the drill by the use of vibration absorption and vibration isolation techniques; and

(ii) evaluate the effectiveness for rock drilling of a hand held mount designed by Bruel and Kjaer for specific use in measuring the level of vibration transmitted to the hand. The need for such a mount arises from the fact that vibration levels measured on the handle of the drill may overestimate the levels transmitted into the hand. The investigation into the use of absorbers and isolators was motivated by a desire to seek a means of reducing vibration levels transmitted to the operator without a major redesign of the drill itself.

4.2 Testing of a Vibration Absorber

If acceleration levels are recorded on the handle of the air leg drill in the direction of drilling and the frequency spectrum of these accelerations is evaluated the results will typically appear as shown in Figure 4.1. As may be seen a dominating influence occurs at the firing frequency F_0 of the drill. Such an observation leads to a first order approximation of the disturbing forces that give rise to the vibrational response as a harmonic force with frequency F_0. Further, simplifying the drill and its air leg by a spring mass representation then the system may be represented as shown in Figure 4.2b where k_L represents the stiffness of the air leg in the Z (drilling) direction, m_D represents the mass of the drill, and P sin $2\pi F_0 t$ represents the excitation applied to the drill where F_0 = blow rate in Hz. Assuming such a representation, then as is well known in vibration theory [2] the addition of a vibration absorber of mass m_A and stiffness k_A where $\sqrt{k_A/m_A} = 2\pi F_0$ will give rise to a reduction in the response of the drill x_D at frequency F_0. The idealized drill

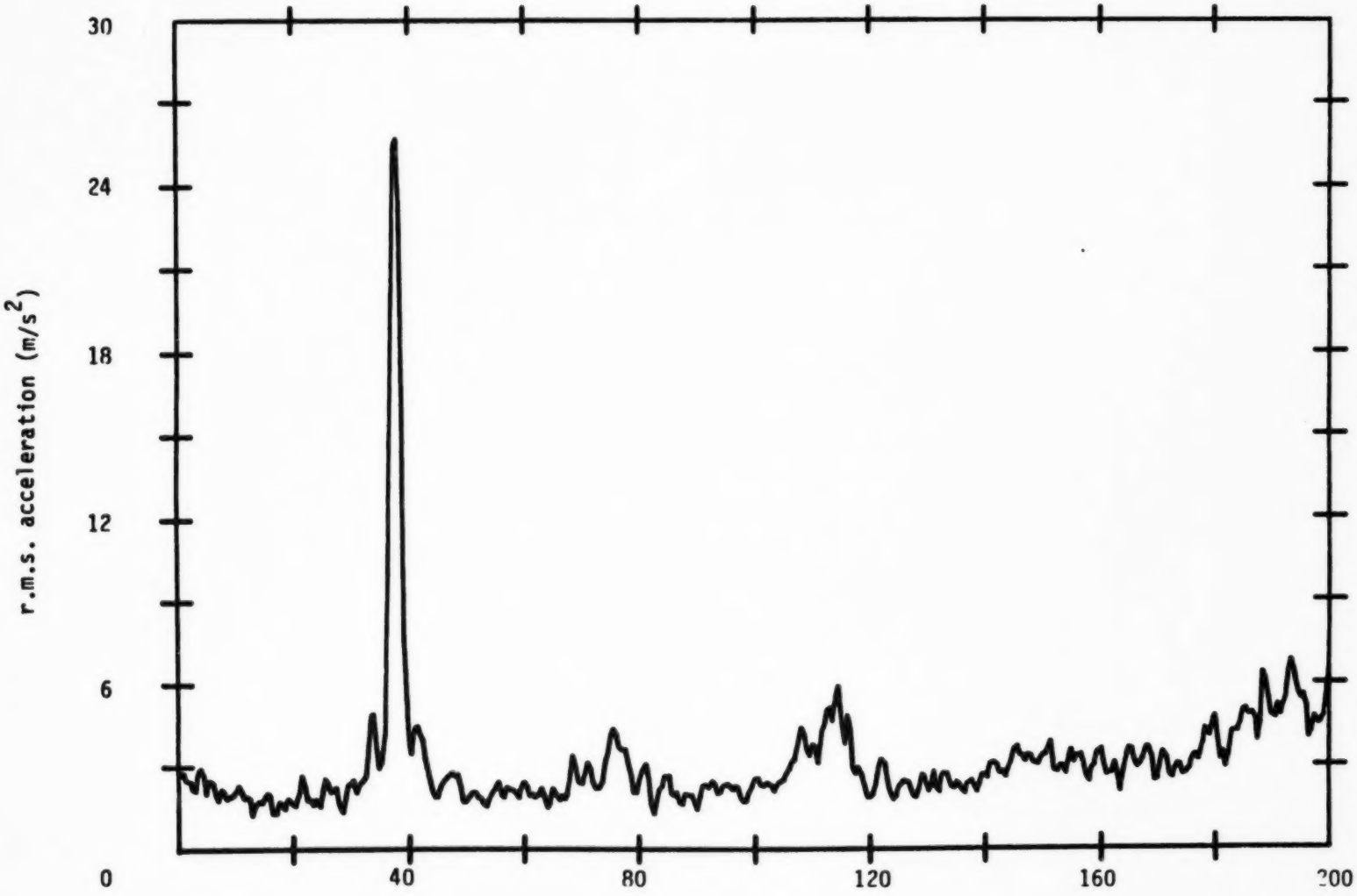
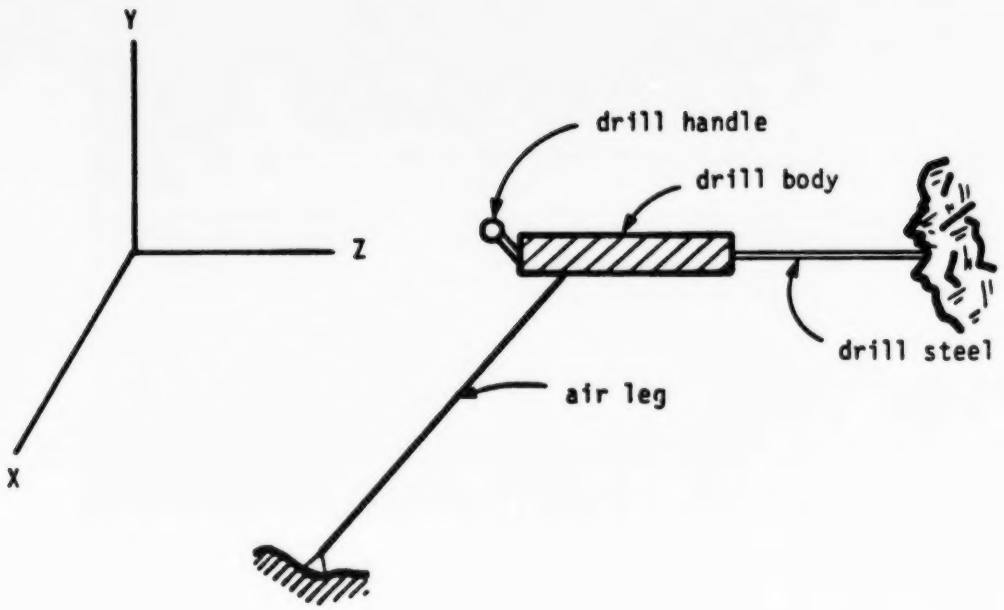
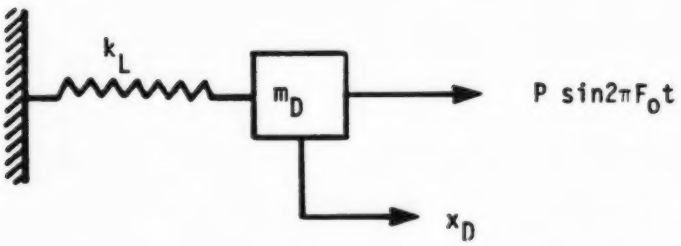


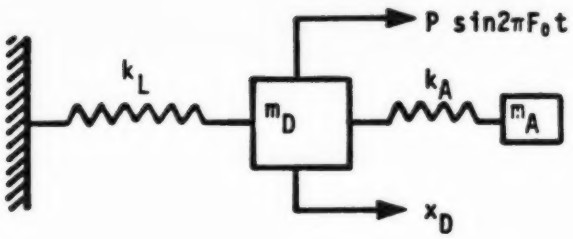
Figure 4.1 ACCELERATION SPECTRUM AT HANDLE OF JACK LEG DRILL



a) Air leg drill



b) Idealization of drill and drilling forces



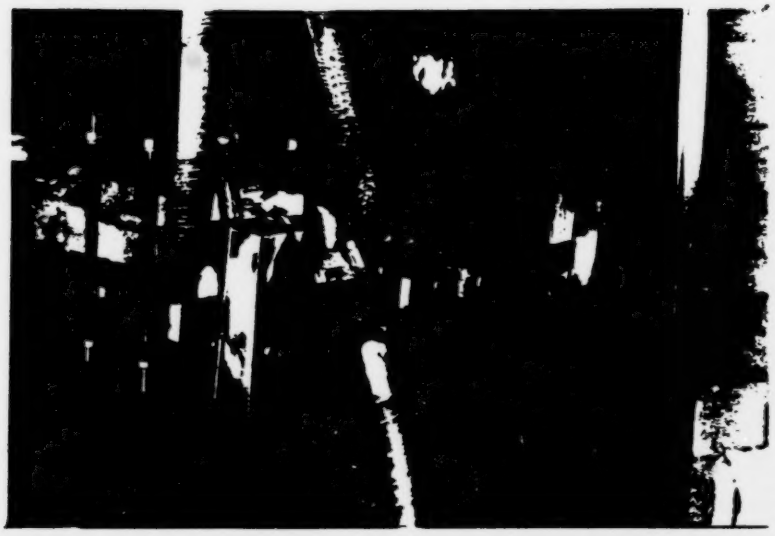
c) Idealized system with vibration absorber

Figure 4.2 IDEALIZED REPRESENTATION OF DRILL AND ABSORBER

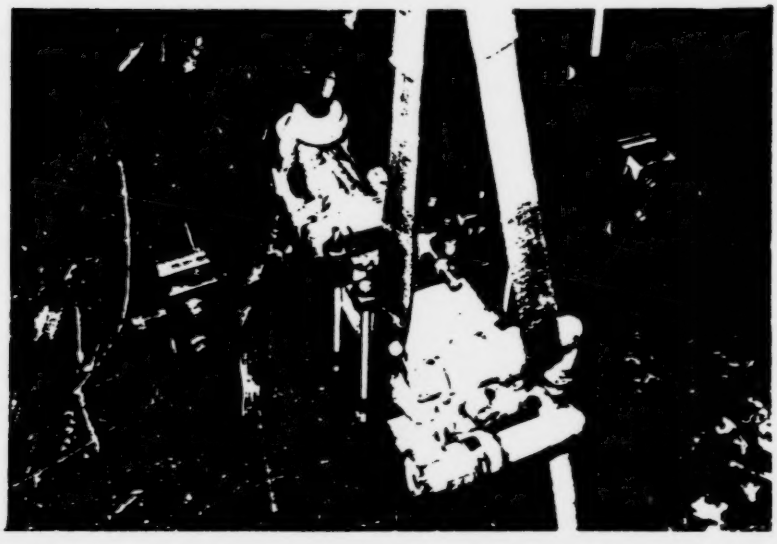
plus absorber is shown in Figure 4.2c. Clearly this model is a gross simplification of the actual system. However the possibility of reducing the vibration level at the blow rate F_0 by such a simple device was sufficiently attractive to pursue this alternative.

In order to test the effectiveness of the concept an absorber was constructed that could be attached to the handle of the drill and consisted of two 5lb weights which could be positioned on cantilevered 1" x 3/8" bars acting as springs. The frequency of the absorber could be tuned by moving the weights, and the whole arrangement was rigidly clamped to the handle of the drill. Initial testing using mild steel bars resulted in failure of the cantilevered arms at the root. Subsequent testing was conducted with 4140 Chrome alloy steel with a yield point of 180,000 psi, and an ultimate strength of 200,000 psi.

Tests were carried out both with the drill idling (see Figure 4.3) and during drilling (see Figure 4.4) into granite rock. The test results obtained during idling at part and full throttle are shown in Figure 4.5. In this figure the RMS cceleration levels at the blow rate frequency F_0 and twice the blow rate frequence $2F_0$ are compared for the drill with and without the absorber. These results were obtained by running the drill with and without the absorber and recording the spectrum (averaged over 32 records) and then comparing the spectrum levels obtained at F_0 and $2F_0$. Such readings were taken for different natural frequencies of the absorber (the natural frequencies of the absorber were found by impacting the absorber when attached to the drill handle.) As may be seen from the figure the results obtained at $2F_0$ show no significant difference whether the absorber is attached or not. This is as would be expected as the



(a) Absorber connected to drill handle.



(b) Absorber connected to drill body.

Figure 4.3 IDLING TESTS OF VIBRATION ABSORBER

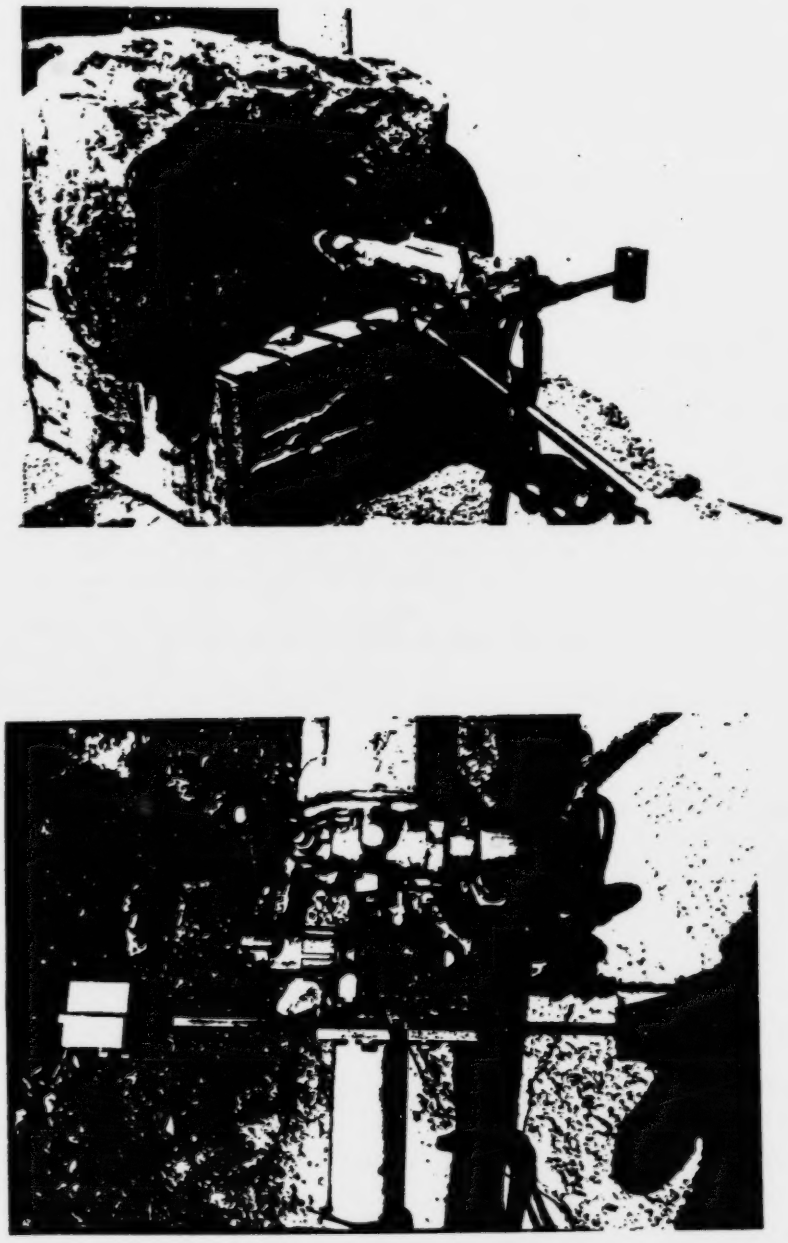


Figure 4.4 DRILLING TESTS OF VIBRATION ABSORBER

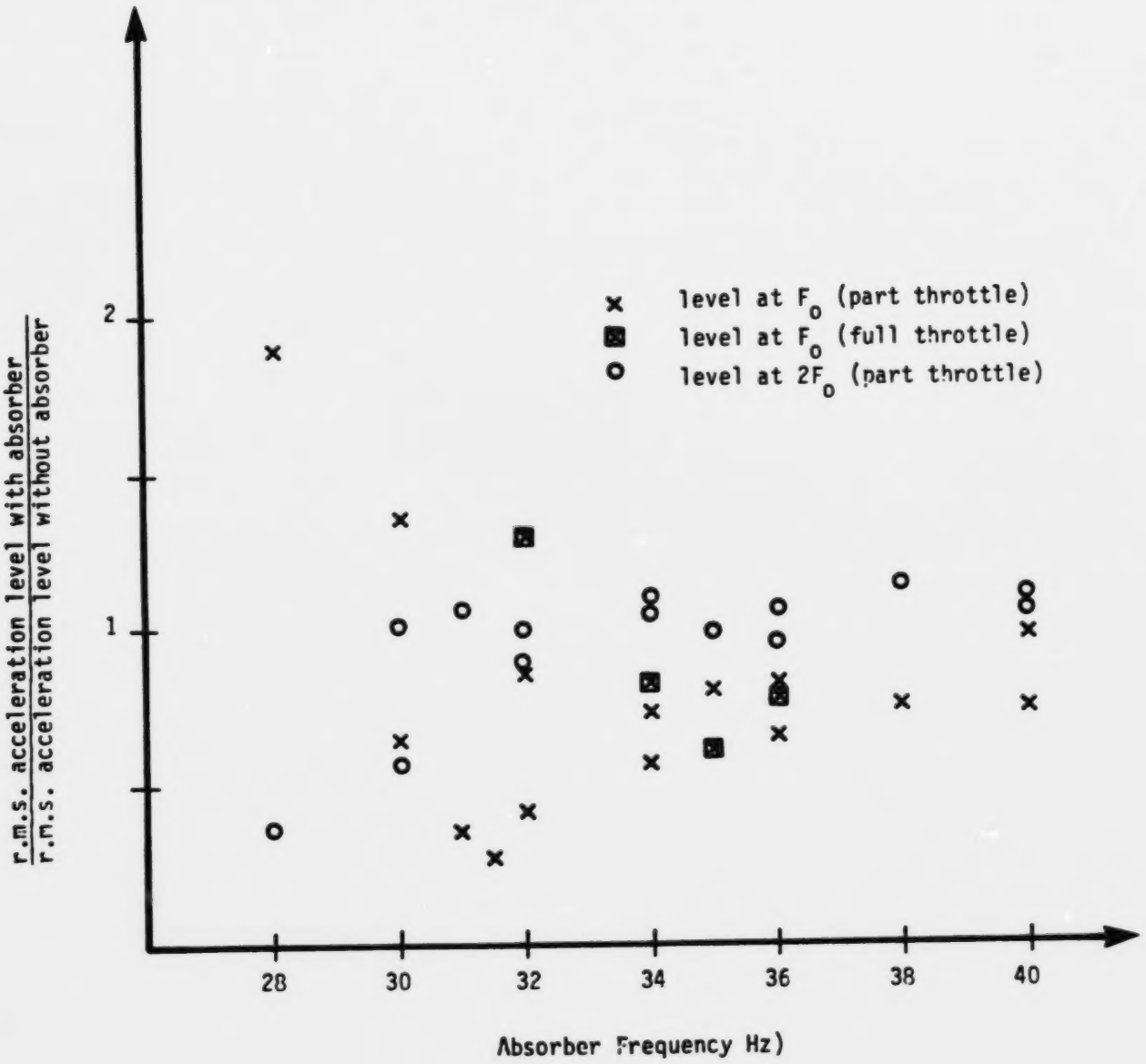


Figure 4.5 EFFECT OF VIBRATION ABSORBER ON IDLING DRILL

absorber is tuned basically to F_0. At F_0 it may be seen that attenuation of the vibration level is obtained in the range 34-36 Hz, although there is significant scatter to the results especially outside this frequency band. In these tests the firing frequency of the drill was approximately 33Hz.

Test results obtained during actual drilling at full throttle are shown in Figure 4.6. These results indicate no significant attenuation of vibration levels for a range of absorber frequencies around the blow rate of 33 Hz. The scatter of the results shown in Figure 4.6 is of the same order as is found between drilling tests conducted under the same nominal conditions.

As significant reductions in vibration levels are required at F_0 in order to satisfy ISO standards it was decided not to pursue, at this stage, further testing of the vibration absorber concept.

Tests were also conducted, during idling, with the absorber attached to the body of the drill (see Figure 4.3b). Again no significant vibration reduction occurred.

4.3 Testing of a Vibration Isolator

As an alternative to the vibration absorber concept, in which an attempt is made to balance the disturbing forces by a secondary system (the absorber) which itself undergoes significant vibrations, is the concept of vibration isolation. In this case an attempt is made to configure the dynamic characteristics of the system such that vibration is isolated from a particular area. In the case of the rock drill, isolation theory indicates that if the handle of the drill were designed to have a fundamental frequency significantly below the

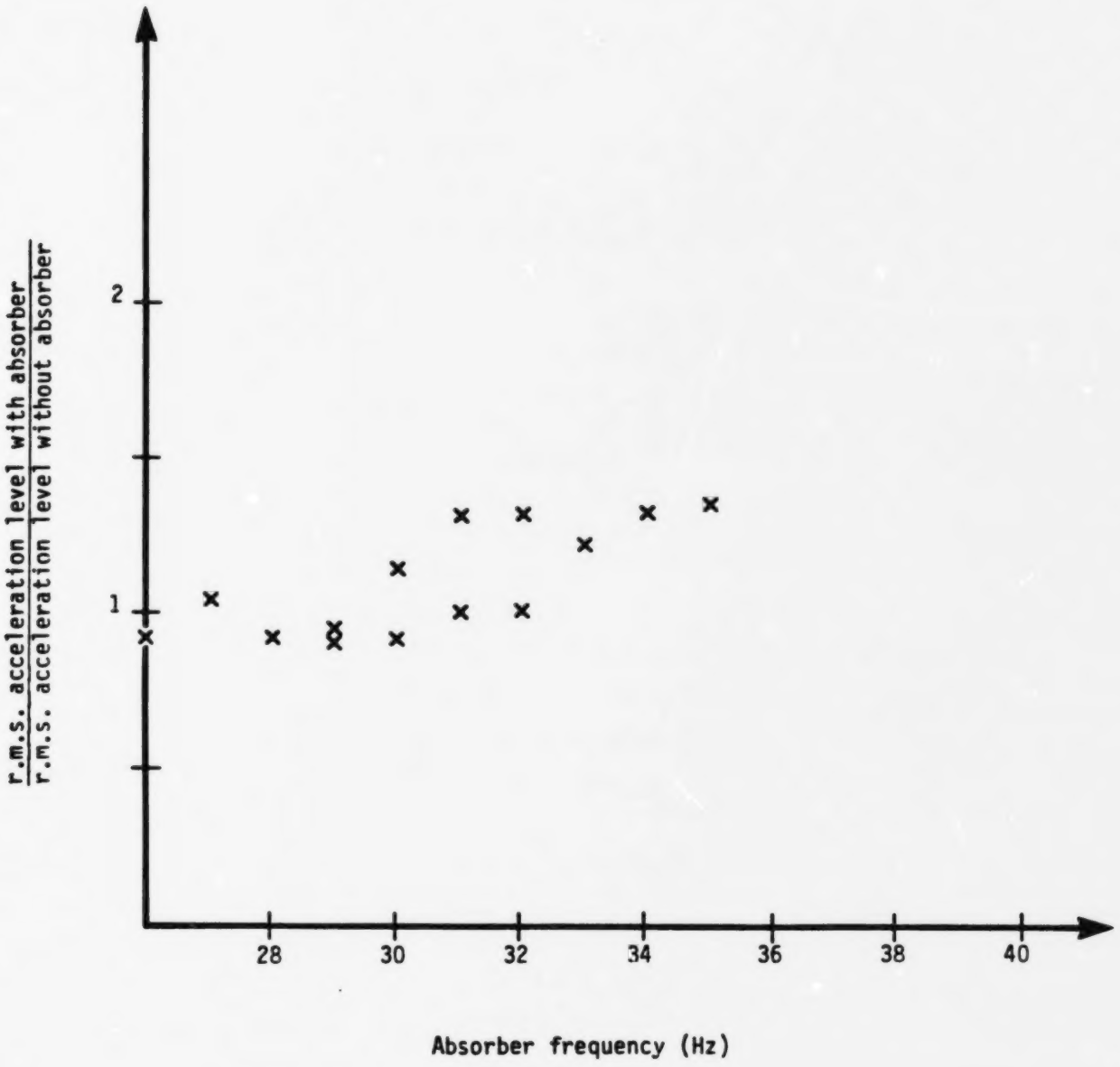


Figure 4.6 EFFECT OF VIBRATION ABSORBER DURING DRILLING

firing frequency (and with no other natural frequencies in the region of this frequency) then the energy at this frequency would be effectively isolated from the handle. In order to investigate this concept a "secondary" handle was designed as shown in Figure 4.7. This secondary handle was attached to the drill handle and serves to test the effectiveness of the concept of modifying the frequencies of the handle. The length L detailed in Figure 4.7 was adjustable in order that the frequency characteristics of the isolator could be varied.

As the primary frequency of the excitation for the drill was known to be approximately 33 Hz, the isolator was designed to have a fundamental frequency of the order of 10 Hz in the Z (drilling) direction. It was also recognized that if any of the natural frequencies of the isolator coincided with any of the major excitation frequencies of the drill then undesirable resonances would be induced. Although no attempt was made in the laboratory tests to design a practical handle it is recognized that the low flexibility associated with a low frequency handle may not be tolerable in the field. It is envisaged that the required stiffness may be achieved by the use of suitably designed rigid stops. In order to test the concept in the laboratory the drill and the attached isolator were suspended from a cradle and the drill run at full throttle for a short time. Acceleration levels were measured simultaneously on the isolator and the drill handle. To investigate the effect of changing the fundamental frequency of the isolator the length L (see Figure 4.7) was varied. The natural frequencies of the isolator were determined by impact testing and are summarized in Table 4.1. In the Z direction the lowest frequency corresponds to the mode where both

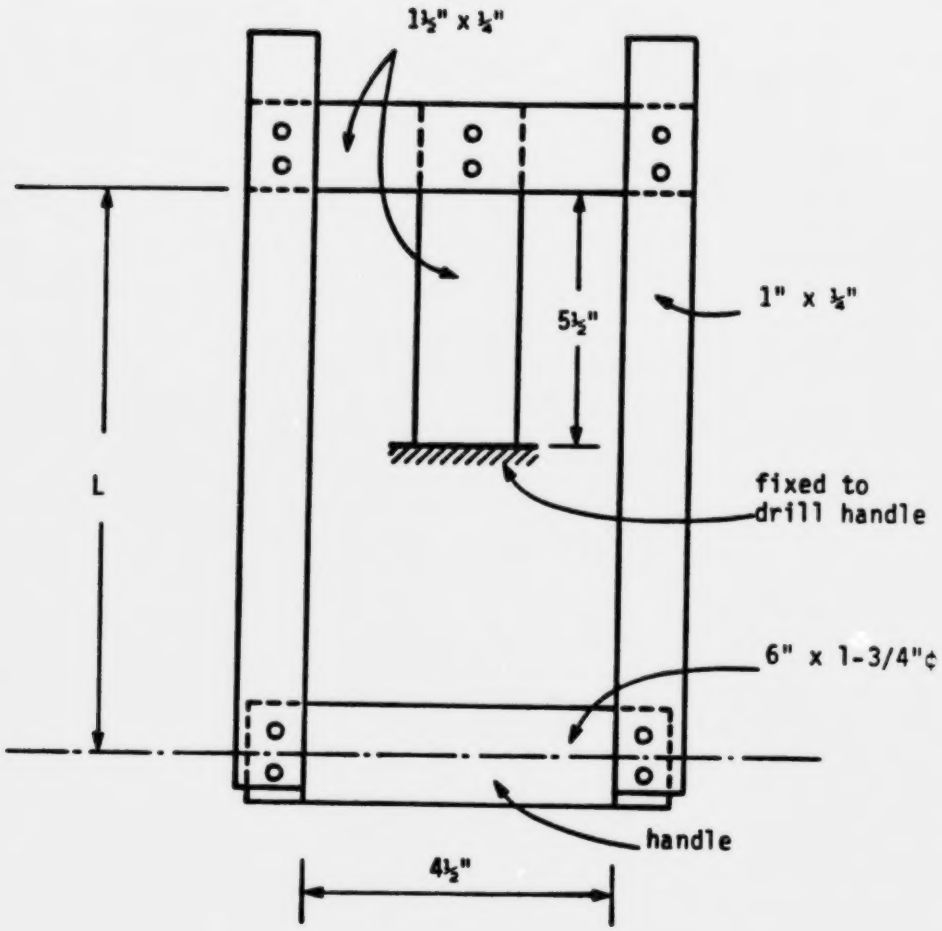


Figure 4.7 DETAILS OF VIBRATION ISOLATOR

TABLE 4.1 NATURAL FREQUENCIES OF ISOLATOR (Hz)

L	Z Direction		Y Direction		
9 3/4"	17	64	25	32	38
11 3/4"	12	54	25	33	38
13 3/4"	10	49	26	33	38

support arms for the isolator handle moved in phase, whereas the second frequency corresponded to the mode where the arms moved out of phase i.e. the mode corresponded to a twisting about the Y axis. As may be noted the natural frequencies in the Y direction are close to the firing frequency and hence amplification may be expected in this direction.

In Figures 4.8 and 4.9 a comparison is presented of the RMS acceleration responses measured on the drill and isolator handles in both the Z and Y directions for the case when L = 13-3/4". In Table 4.2 the acceleration levels recorded at frequencies F_0 and $2F_0$ for the three different configurations of the isolator are given. As may be noted significant reductions in vibration levels were obtained in the Z direction at both F_0 and $2F_0$. In the Y direction no such significant reduction occurred as may be anticipated as there did not exist any low frequency coupling between the drill and isolator handle

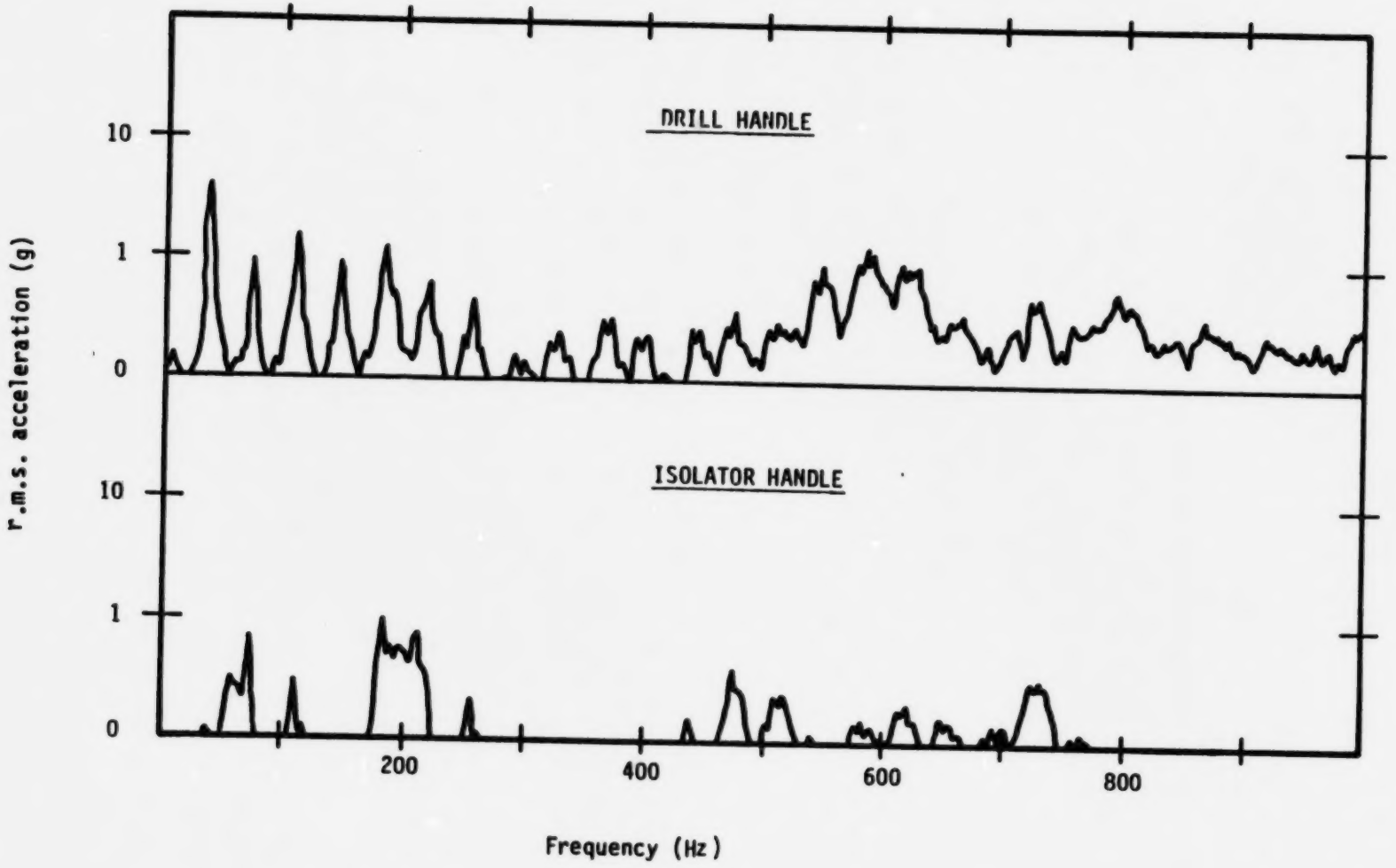


Figure 4.8 EFFECT OF ISOLATER ON R.M.S. ACCELERATIONS IN Z-DIRECTION

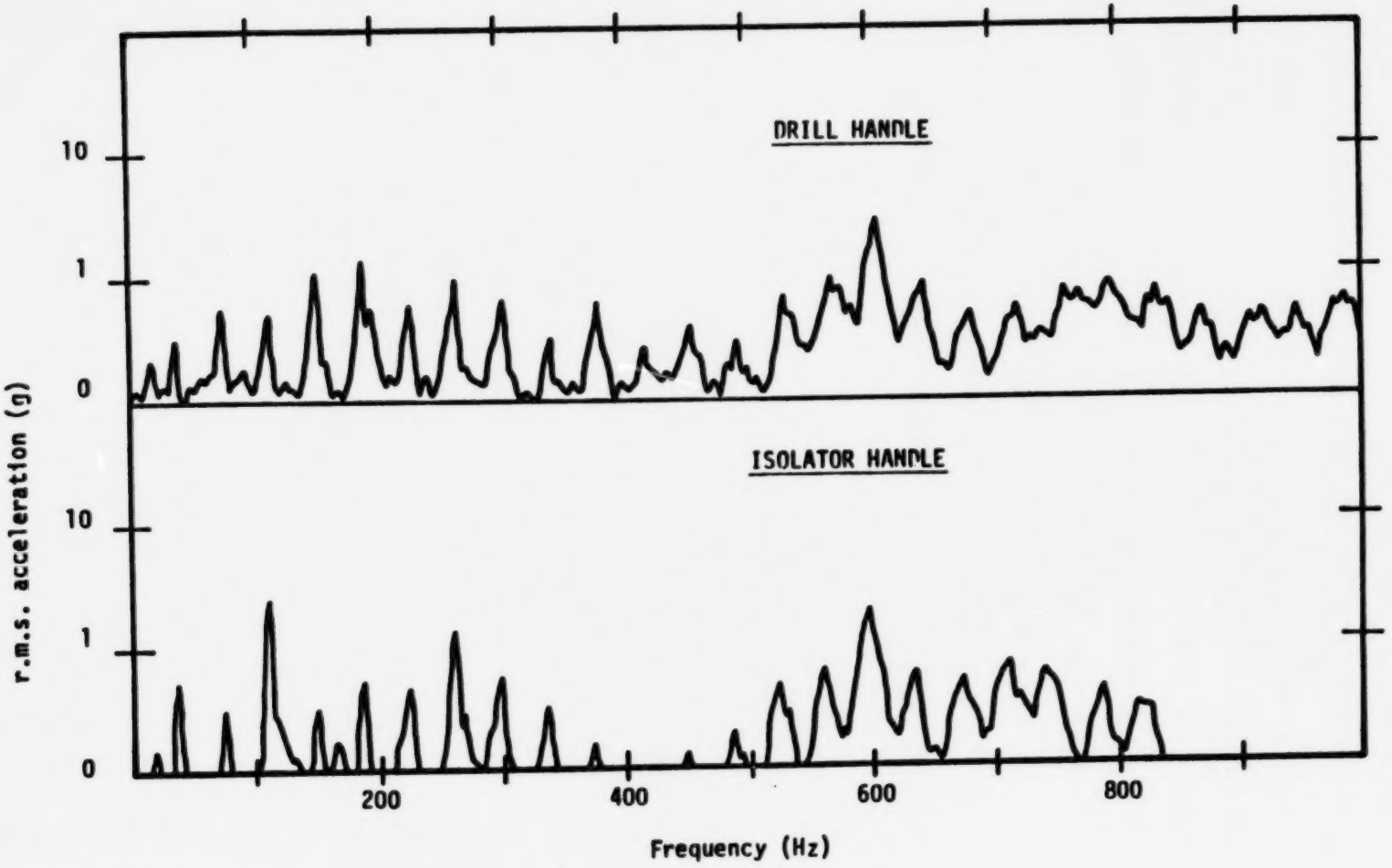


Figure 4.9 EFFECT OF ISOLATOR ON R.M.S. ACCELERATION IN Y-DIRECTION

TABLE 4.2 COMPARISON OF ACCELERATION LEVELS (m/s^2) BETWEEN DRILL AND ISOLATOR HANDLE [IDLING TESTS]

	Z Direction		Y Direction	
	F_0	$2F_0$	F_0	$2F_0$
Drill Handle	44	23	5	14
Isolator Handle				
L = 9 3/4"	17	5	3	1
L = 11 3/4"	2	4	5	5
L = 13 3/4"	2	4	5	11

Table 4.3 COMPARISON OF ACCELERATION LEVELS (m/s^2) BETWEEN DRILL AND ISOLATOR HANDLE

Drill Handle	27	26	23
Isolator Handle	3	3	4

in the Y direction. In fact the isolators had natural frequencies in the Y direction close to the firing frequency of 33 Hz which explains why in some tests amplification of the vibrations occurred in the Y direction. A series of tests were conducted to evaluate the performance of the isolator during drilling conditions (see Figure 4.10). Table 4.3 shows a comparison of the acceleration levels measured on the drill handle with those measured on the isolator handle. These results were recorded at the firing frequency F_0 = 33 Hz and the isolator had a fundamental frequency of 12 Hz. As may be noted in two of the three tests the levels were reduced by a factor of 10.

The results obtained in the Y direction gave an amplification of the acceleration levels by a factor of approximately three. As has been mentioned this was probably caused by a natural frequency in the Y direction close to the firing frequency. Further testing would be desirable in order to modify the isolator's dynamic characteristics in the Y direction to eliminate this problem.

The test results presented indicate that if service requirements with regard to handle flexibility can be met then a suitably designed drill handle may well reduce the vibration levels by an extent that would be significant in terms of delaying the onset of VWFD symptoms.

Figure 4.10 DRILLING TESTS OF THE VIBRATION ISOLATOR

4.4 Laboratory Testing of Hand-Held Vibration Mount

In evaluating the effects of vibration transmitted through the hand ISO 5349 "Principles for the Measurement and Evaluation of Human Exposure to Vibration Transmitted to the Hand" is often used as the relevant standard. In the latest version this standard it is prescribed that vibration levels should be measured on the handle of the drill. In order to attempt to measure more accurately the vibration levels transmitted into the hand the instrument manufacturer Bruel and Kjaer have developed the hand held vibration mount shown in Figure 4.11. The base of the mount is held by the drill operator against the handle of the drill and the location of the accelerometers has been designed to correspond closely with that specified by previous versions of ISO 5349. The mount has been designed to accept three miniature accelerometers in three orthogonal directions although it may be noted that supporting field instrumentation, namely Bruel and Kjaer 2513 Integrating kibration Meter, is only able to process data from one channel at a time. The 2513 Integrating Vibration Meter outputs 1 minute averages of the recorded vibration levels to a C101 data storer which has sufficient memory to store data for up to 25 hours. The 2513 and C101 may be enclosed in a protective box and attached to the operator, as shown in Figure 4.12. The operator can then, at least in theory, collect data that will represent his vibration exposure for the period of his shift. At the end of the shift the data may be output to a Bruel and Kjaer Alpha numeric Printer type 2312 which provides a hard copy record of the vibration levels. In practice the mount and trailing cables are not appropriate for general use in a mine. Attempts were made to use this set up in the underground tests conducted at the Westmin mine. However problems

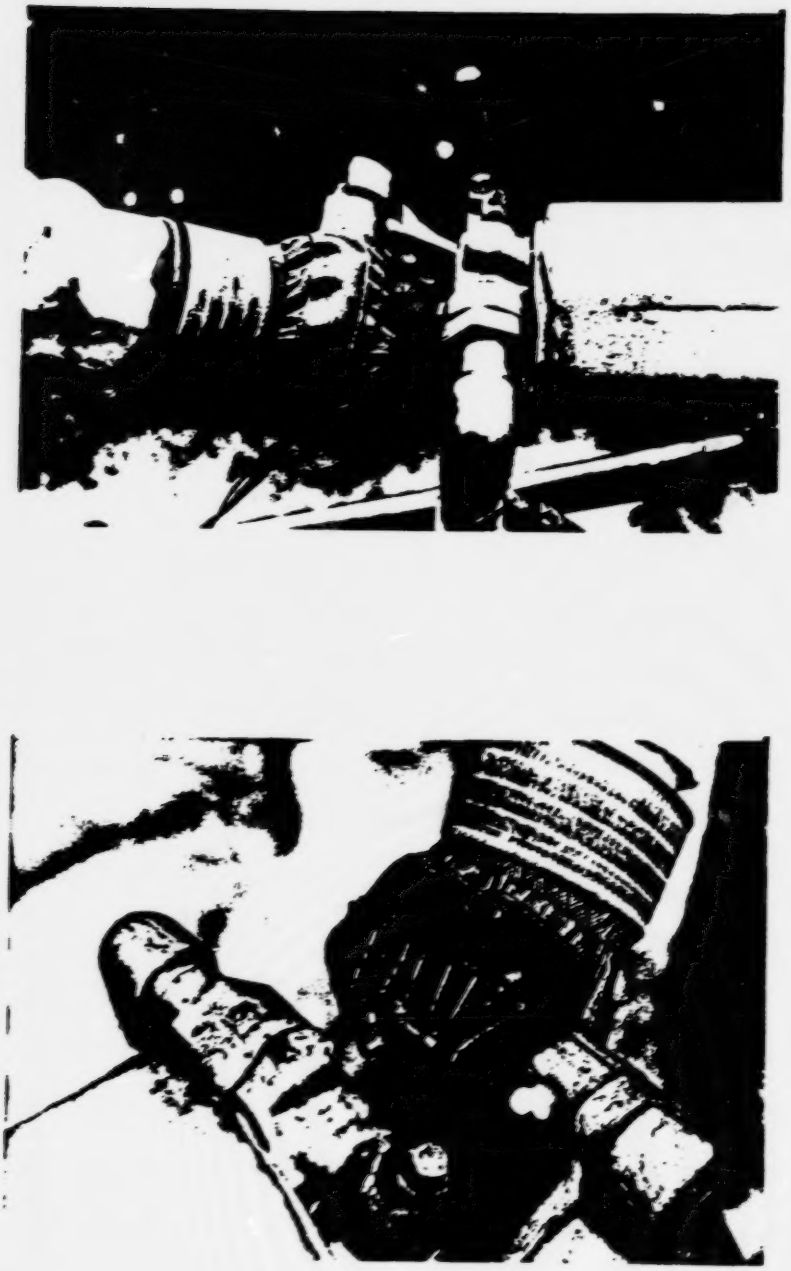


Figure 4.11 HAND HELD VIBRATION MOUNT

Figure 4.12 HAND HELD MOUNT CONNECTED TO VIBRATION METER AND DATA STORER ENCLOSED IN PROTECTIVE CASING

with the instrumentation prevented readings from being taken. Further, the mount is not appropriate for use in its present form except for a well controlled test run. For general monitoring purposes all attachments must be more ruggedly designed. It is conceivable that attaching the 2513 and C101 in a protected casing attached to the drill, and then attaching the accelerometer directly to the handle in another protective casing with a steel hose connecting the two may constitute a practical way of obtaining exposure readings for a complete shift.

Drilling tests were conducted with the mount to (i) compare acceleration levels obtained on the drill handle with those obtained on the mount and (ii) to simultaneously measure the XYZ components recorded on the mount.

In Table 4.4 the RMS acceleration levels obtained on the handle and on the mount are compared. These results indicate (as did subsequent tests) that levels recorded in the Z direction were very much the same on the handle as on the mount but that in the X and Y directions the levels recorded at the mount were significantly higher than those recorded on the handle. These results were obtained with the operator of the drill holding the mount against the drill handle. However if the mount were rigidly clamped to the handle the readings in all three directions were comparable.

A further test was conducted in which accelerations were recorded simultaneously in the X Y and Z directions. These results are presented in Table 4.5. Once again it is observed that the Y and X levels are relatively high compared to the results obtained on the drill handle.

It would appear from the results obtained that the usual

TABLE 4.4 COMPARISON OF HANDLE AND MOUNT RMS ACCELERATION LEVELS(m/s^2)

Direction		X	Y		Z	
Handle:	F_0	3	4	7	19	20
	$2F_0$	1	5	2	6	9
Mount:	F_0	6	17	9	18	15
	$2F_0$	9	2	4	12	7

TABLE 4.5 RMS ACCELERATION LEVELS (m/s^2) AT MOUNT IN X, Y, Z DIRECTIONS

Direction	X					Y					Z				
F_0	4	4	4	1	2	19	7	14	14	14	10	9	9	11	11
$2F_0$	2	2	4	1	2	10	4	9	8	12	3	2	4	3	4

assumption that the acceleration level in the Z direction is the highest [as it is at the handle] is not necessarily true at the location of the mount. Thus using the mount to obtain uniaxial readings in the Z direction may give an erroneous picture of the maximum acceleration level at the location of the mount. In order to define the exact vibration level requires therefore, that simultaneous readings be taken in three orthogonal directions. At the present time the instrumentation available to do this is not well suited to obtaining results in a mine environment. A further complication in using the mount to obtain uniaxial measurements arises from the fact that a drill operator rarely keeps his hand oriented in a fixed direction during drilling, whence the readings obtained from the mount correspond to accelerations in different and undefined directions.

Thus it may be seen that serious complications arise in attempting to measure appropriate vibration levels using the mount. A question that naturally arises is whether, given the unknowns of the problem and the inherent scatter of the data obtained, any real benefit is accrued by attempting to measure vibration levels at locations other than on the handle of the work piece; and indeed, the latest version of ISO 5349 (Revised Sept. 1982) specifies that measurements should be taken on the handle of the drill.

4.5 Conclusions

From the laboratory and drilling tests conducted it has been demonstrated that

(i) attaching a vibration isolator to the handle of an air leg rock drill can lead to significant reductions in the level of vibrations transmitted

(ii) attaching a vibration absorber to the drill did not result in significant reductions in vibration levels.

(iii) the hand held mount and corresponding instrumentation designed specifically for measuring hand held vibration is not well suited to the problem of obtaining vibration measurements in a mine.

The results obtained relating to the vibration isolator indicate that further work in this area would be desirable. Specifically it would be worthwhile to develop a handle designed itself to act as an isolator.

5. COMPUTER INTERFACING OF EXISTING VIBRATION INSTRUMENTATION

5.1 Introduction

The well known instrumentation manufacturer Bruel and Kjaer has developed specific instrumentation for the measurement and recording of vibration that extends over a prolonged period of time. This instrumentation, which is intended to be of particular use in the measurement and recording of hand-arm vibration, consists of a number of components:

(i) Integrating Vibration Meter Type 2513

This hand sized meter has a thermometer type display and records either vibration velocity or acceleration with a choice of RMS, max-RMS, peak and peak/60s L_{eq} indications. The meter incorporates an electronic weighting filter to permit measurements to be made in accordance to ISO Draft 5349, in this mode the instrument will produce each minute a d.c. pulse representative of the weighted acceleration level that can be stored on a data storer.

(ii) Data Storer Type C101

This is a battery powered unit, that can be attached to the 2513, capable of storing one minute averages passed from the 2513 for periods up to 25 hours.

(iii) Data Processor Type C102

The instrument is designed to read and manipulate data fed from the data storer type C101.

(iv) Alphanumeric Printer Type 2312

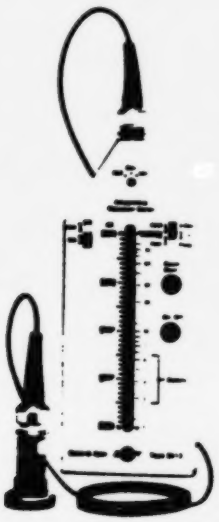
This is a low power battery operated alphanumeric printer which conforms to IEC 625-1 Interface Bus Standard and can be used to produce a hard copy record of the data in the C102 unit. In Figure 5.1 each of these instruments is illustrated and in Figure 5.2 a typical output from the Alphanumeric Printer Type 2312 is shown.

With the growing usage of computers it was felt that any instrumentation that stored considerable quantities of data would in the future need to be capable of interfacing to a computer in such a way that the data could be easily presented by graphical means and a convenient hard copy record be made readily available. To this end it was required as part of the contract to investigate the possibility of interfacing the existing Bruel and Kjaer instrumentation to a computer. It was suggested that initially the possibility of eliminating the 2312 printer should be investigated, however it was decided after an investigation of the problem that data could be transferred directly to a computer from the Data Storer Type C101. The interfacing that was done was to a PDP 11/34 as such a machine was available for this work, interfacing to other computers that have an RS 232 port will follow the same lines.

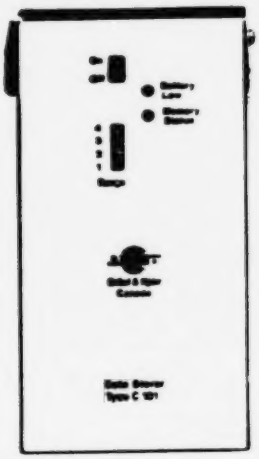
5.2 RS 232 Interface of a Bruel and Kjaer C101 Data Storer and a Computer

The Bruel and Kjaer C101 Data Storer is a portable analogue to digital converter for use with several Bruel and Kjaer sound level and vibration meters. The output from the meter is

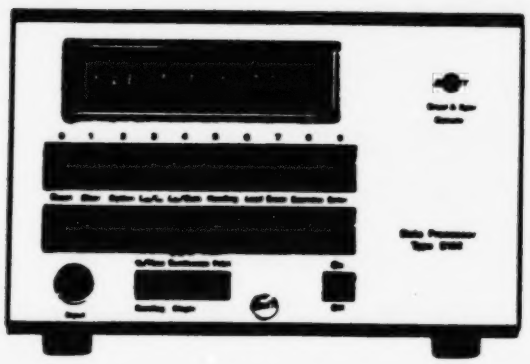
Integrating Vibration Meter Type 2513



Data Storer Type C 101



Data Processor Type C 102



Alphanumeric Printer Type 2312

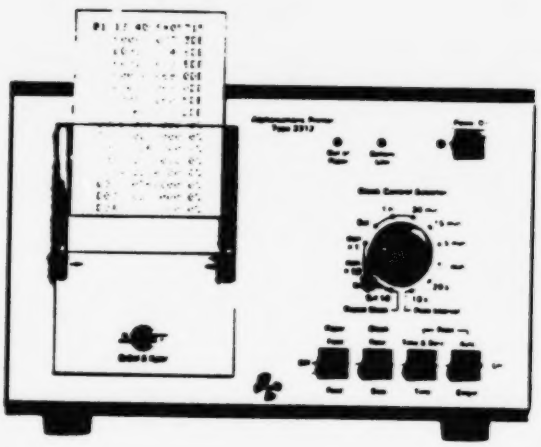


Figure 5.1 DATA COLLECTION AND RECORDING INSTRUMENTATION

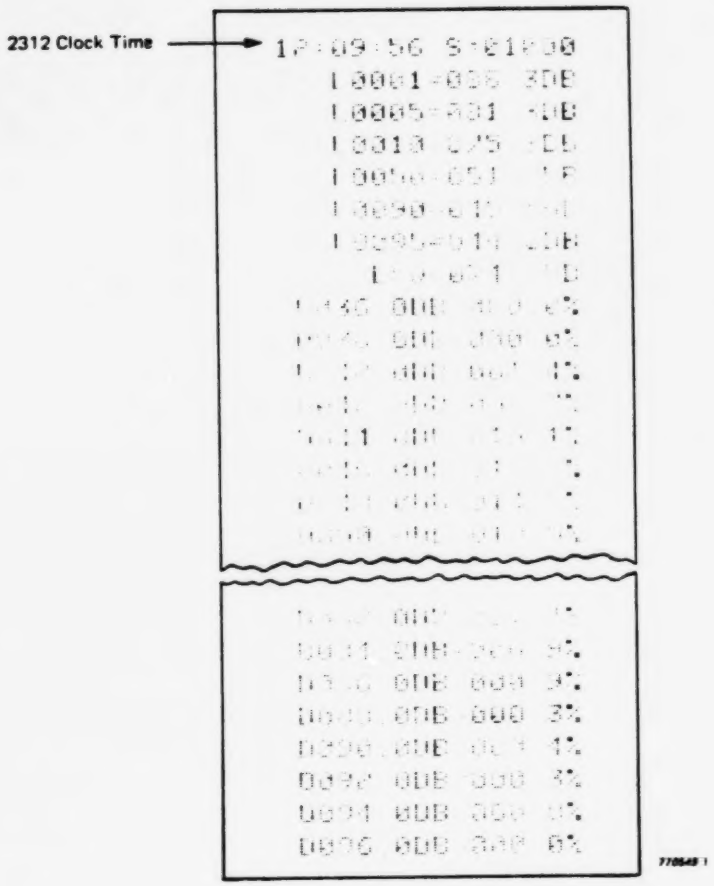


Figure 5.2 OUTPUT FROM PRINTER TYPE 2312

converted from a voltage to a digital number and stored in nonvolatile memory in the C101.

The problem of interfacing the C101 to the PDP 11/34 was divided into three parts: first it was necessary to understand the code used by the C101 to output its data; second it was necessary to design a hardware interface between the C101 and the PDP 11/34 and finally it was necessary to write a computer program to read and translate the data.

C101 Data Format

The C101 transmits all its data as ASCII characters. The first character is always a "?". This is always followed by a range specifier, that identifies the offset that must be added to the data to obtain the value read by the C101. The range specifiers are as follows: range "1" gives an offset of 20 dB, range "2" gives an offset of 50 dB, range "3" gives an offset of 80 dB and range "4" gives an offset of 100 dB. This combination of "?" and a range specifier is also used to separate the different files in the C101.

Each data point is output from the C101 as a pair of ASCII characters. To recreate the data point it is necessary to combine the pair of characters into one eight bit byte. This is done by discarding all but the four least significant bits of the two characters. This pair of four bit nibbles are then combined to make the eight bit byte, with the nibble from, the first character forming the most significant nibble of the data byte

and the nibble from the second character forming the least significant nibble of the data byte. Bits 0 and 1 of this byte form the decimal part of the data value and bits 2 to 7 form the integer part of the data value. Figure 5.3 one shows how the bits are rearranged and give an example showing how to convert the character pair "7" and "4" to a data value. Once the data value has been extracted from the characters the range offset has to be added in to get the final number.

The end of the data is indicated by the C101 sending the character "X".

Hardware Interface:

Data is transferred from the C101 in the following manner. The terminal line on the C101 (pin 7) is normally low. The C101 is "armed" by bringing this line high. The send line (pin 4) is normally high. Data transfer is started by bringing this line low. When the send line is low data is transmitted on the data out line (pin 2).

The way this was implemented is as follows. The send line (pin 4), the digital ground (pin 8) and the transitor switch base input (pin 9) were wired together. The 6 volt supply line (pin 6) and the terminal line (pin 7) were wired together through a 1.1 K ohm resistor. The data output line (pin 2) of the C101 was connected to the data out line (pin 2) of an RS232C connector. Finally the ground line (pin 8) of the C101 was connected to the ground line (pin 7) of the RS232C connector. Figure 5.4 is a diagram of how the connections were made.

1st character 011 HGFE

2nd character 001 DCBA

Data Byte H G F E D C B A

integer decimal

Note: for B A = 00, then the decimal = 0.00
for B A = 01, then the decimal = 0.25
for B A = 10, then the decimal = 0.50
for B A = 11, then the decimal = 0.75

For example the character pair "7", "5" would be converted as follows:

ASCII "7" = Octal 67 = 011 0111
ASCII "5" = octal 64 = 011 0101

data byte = 0111 0101

Integer = 011101 = 29.
decimal = 01 = .25
29.25

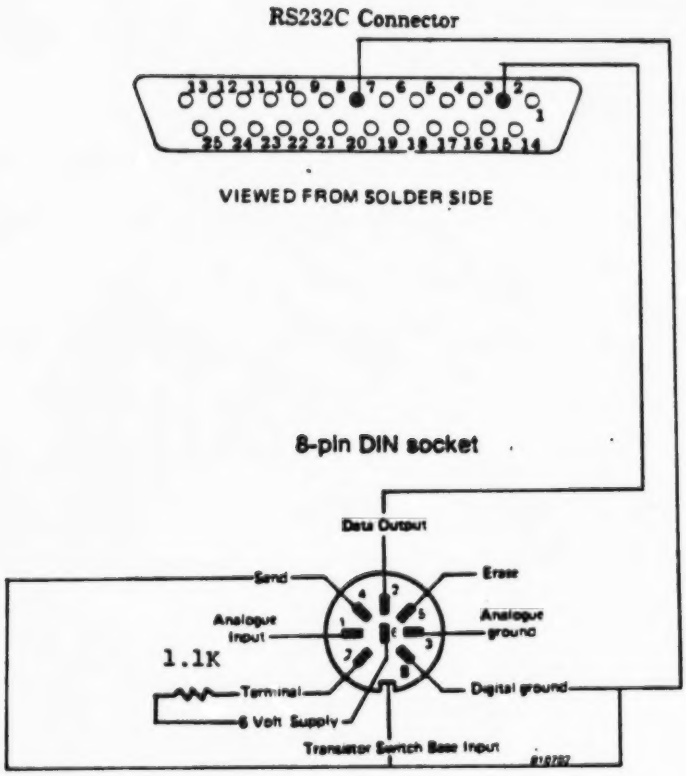


Figure 5.4 INPUT/OUTPUT SOCKET PIN CONNECTIONS SHOWN LOOKING INTO THE SOCKET

Computer Program

A listing for the computer program is given in the Appendix. The comments in the program should make it self explanatory. As it is written the program will only receive a maximum of 200 characters from the C101. This number may have to be increased. The amount of space necessary can be calculated as follows, each data point requires two characters, each file requires two characters and the end of data requires one character. The number calculated should replace the 200 in lines 3 and 15 of the program.

It should be noted that the C101 does not do any handshaking in either hardware or software, therefore it is necessary to run the program with a fairly high priority to insure that no data is lost. In our case we ran with a priority of 200.

5.3 Conclusions

With the development of a computer interface for the data storer not only are the data processor and the printer not required but the data manipulation and presentation possibilities, for the data stored in the C101, are only limited by the scope of software available for the computer. Thus in general, data manipulation, file storaage and graphical presentation can all be readily accomplished. Such an arrangement would be ideally suited to the needs of a mine requiring to make regular data checks and be able to quickly compare with previously obtained information.

6. REFERENCES

1. Hutton, S.G., and Brubaker, R., "The Effect of Vibration Upon Workers in the Mining Industry." Contract Report submitted to D.S.S. Energy Mines and Resources, 1980.

2. Den Hartog, J.P., Mechanical Vibrations, McGraw Hill Book Company.

7. APPENDIX

This appendix contains computer programs to:

(i) Interface between a Bruel and Kjaer C101 data storer and a PDP 11/34 computer;

(ii) Calculate 4 hour frequency-weighted acceleration level according to ISO DIS 5349 from data output from a Nicolet 660A spectrum analyzer; and

(iii) Calculate third octave analysis of data output from a Nicolet 660A spectrum analyzer.

```
FORTRAN IV      V02.5-11        TUE 08-MAR-83 11:15:35          PAGE 001
,BNK=BNK

      C
      C     THIS PROGRAM READS THE DATA FROM THE B AND K C101
      C
      C
0001          LOGICAL*1 INBUF
0002          INTEGER INSB(2),DSW,OUTSB(2),INPAR(6),OUTPAR(6)
0003          LOGICAL*1 STORE(200)
0004          BYTE BUF(80)
      C
      C     SET UP FOR THE QIO CALLS
      C     INSB,INPAR,INBUF ARE INPUT ARRAYS
      C
0005          CALL GETADR(INPAR(1),INBUF)
0006          INPAR(2)=1
      C
      C     FIND THE TERMINAL PORT THAT THE C101 IS ATTACHED TO
      C
0007          WRITE(5,910)
0008    910   FORMAT(' WHICH TERMINAL PORT IS THE C101 ATTACHED TO? ',$)
0009          READ(5,915) (BUF(I),I=1,80)
0010    915   FORMAT(80A1)
0011          L=LENGTH(BUF,80)
0012          BUF(L+1)=0
      C
      C     OPEN THE TERMINAL PORT AS LU ONE
      C     AND OPEN THE OUTPUT FILE AS LU TWO
      C
0013          CALL ASSIGN(1,BUF)
0014          CALL ASSIGN(2,'BNK.DAT')
      C
      C     NOW DO THE I/O
      C     NOTE: 88 = "X" WHICH MARKS THE END OF THE DATA
      C
0015          DO 100 I=1,200
0016          CALL WTQIO("1020,1,3,,INSB,INPAR)
0017          STORE(I)= INBUF
0018          IF (INBUF .EQ. 88) GOTO 110
0020    100   CONTINUE
0021          WRITE(5,900)
0022    900   FORMAT(' DATA OVERFLOW')
0023          GOTO 999
      C
      C     SET NUMBER OF POINTS
      C
0024    110   NDATA=I-1
      C
      C     CONVERT TO NUMBERS
      C
      C
      C     CHECK FOR NEW FILE
      C     NOTE: 63 = "?" WHICH IS THE NEW FILE MARKER
      C
0025          IF (STORE(1) .NE. 63) GOTO 999
      C
```

```
      C     SET FILE COUNT TO 0
      C
0027        IFILE=0
      C
      C     LOOP THRU DATA
      C
0028        DO 200 I=1,NDATA-1,2
      C
      C     CHECK FOR NEW FILE
      C     NOTE: 63 = "?" WHICH IS THE NEW FILE MARKER
      C
0029        IF (STORE (I) .NE. 63) GOTO 210
0031        IFILE=IFILE+1
0032        CALL RANGE(STORE(I+1) ,R)
0033        GOTO 200
      C
      C     CONVERT TO NUMBER
      C
0034  210   CALL ASTONB(STORE(I), STORE(I+1), ANSWER)
      C
      C     ADD IN RANGE
      C
0035        VALUE = ANSWER + R
      C
      C     OUTPUT THE FILE NUMBER AND THE VALUE OF THE READING
      C
0036        WRITE(2,940) IFILE,VALUE
0037  940   FORMAT(1X,I4,F10.2)
      C
      C     LOOP UP FOR NEW VALUE
      C
0038  200   CONTINUE
0039  999   STOP
0040        END
```

FORTRAN IV STORAGE MAP FOR PROGRAM UNIT .MAIN.

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000532 (173. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
ANSWER	R*4	000520	DSW	I*2	000502	I	I*2	000504
IFILE	I*2	000512	INBUF	L*1	000500	L	I*2	000506
NDATA	I*2	000510	R	R*4	000514	VALUE	R*4	000524

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
BUF	L*1	$DATA	000350	000120 (40.)	(80)
INPAR	I*2	$DATA	000010	000014 (6.)	(6)
INSB	I*2	$DATA	000000	000004 (2.)	(2)
OUTPAR	I*2	$DATA	000024	000014 (6.)	(6)
OUTSB	I*2	$DATA	000004	000004 (2.)	(2)
STORE	L*1	$DATA	000040	000310 (100.)	(200)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*4	ASTONB	R*4	GETADR	R*4	LENGTH	I*2	RANGE	R*4
WTQIO	R*4								

```
      C
      C
      C
      C
      C     SUBROUTINES
      C
      C
      C
0001        SUBROUTINE RANGE(X,R)
      C
      C     THIS SUBROUTINE FINDS THE RANGE FOR THE READINGS TO FOLLOW
      C
0002        LOGICAL*1 X
0003        REAL R
      C
      C     FIND RANGE
      C
0004  300   IF(X .EQ. 49) GOTO 20
0006        IF(X .EQ. 50) GOTO 50
0008        IF(X .EQ. 51) GOTO 80
0010        IF(X .EQ. 52) GOTO 100
0012        WRITE(5,900)
0013  900   FORMAT(' BAD RANGE ')
0014  20    R=20.
0015        RETURN
0016  50    R=50.
0017        RETURN
0018  80    R=80.
0019        RETURN
0020  100   R=100.
0021        RETURN
0022        END
```

```
FORTRAN IV STORAGE MAP FOR PROGRAM UNIT RANGE

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000004 (     2. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET
R      R*4 @ 000002     X      L*1 @ 000000
```

```
      C
      C
      C
0001        SUBROUTINE ASTONB(I,J,X)
      C
      C     THIS SUBROUTINE CONVERTS THE PAIR OF ASCII CHARACTERS INTO A NU
      C     CORRESPONDING TO THE READING TAKEN BY THE B AND K C101
      C
0002        LOGICAL*1 I,J
0003        REAL X
      C
      C     STRIP OFF THE TOP 4 BITS
      C
0004        I=I-48
0005        J=J-48
      C
      C     FIND THE DECIMAL
      C
0006        DEC=(FLOAT(J)/4.) - FLOAT (J/4)
      C
      C     COMBINE THE PARTS
      C
0007        X=FLOAT(I*4 + J/4) + DEC
0008        RETURN
0009        END
```

```
FORTRAN IV STORAGE MAP FOR PROGRAM UNIT ASTONB

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000020 (     8. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET
DEC    R*4   000006     I      L*1 @ 000000     J      L*1 @ 000002
X      R*4 @ 000004

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE   NAME   TYPE
FLOAT   R*4
```

```
      C
      C     THIS FUNCTION FINDS THE LENGTH OF A LINE
      C
0001        INTEGER FUNCTION LENGTH (BUF,N)
0002        BYTE BUF(1),BL
0003        INTEGER N
0004        DATA BL/32/
      C
      C     LOOP TO FIND LAST LETTER
      C
0005        DO 100 I=N,1,-1
0006        IF (BUF(I) .NE. BL ) GO TO 200
0008  100   CONTINUE
0009  200   LENGTH =I
0010        RETURN
0011        END
```

```
FORTRAN IV STORAGE MAP FOR PROGRAM UNIT LENGTH

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000014 (    6. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET
BL     L*1   000006     I      I*2   000012     LENGTH I*2   000004 Eqv
N      I*2 @ 000002

LOCAL AND COMMON ARRAYS:

NAME     TYPE   SECTION OFFSET  ------SIZE----- DIMENSIONS
BUF    L*1    @ $DATA   000000  000001 (    1.) (1)
```

AHW,AHW=AHW

```
      PROGRAM AHW
***** C
      C
      C       THIS PROGRAM CALCULATES 4 HOUR FREQUENCY-WEIGHTED
      C       LEVEL ACCORDING TO ISO DIS 5349(JAN 82) FOR A SET
      C       OF USER SELECTED DATA FILES. IT THEN CALCULATES
      C       FOR THIS SET:
      C            MEAN VALUE
      C            STANDARD DEVIATION (S.D.)
      C            MAXIMUM VALUE
      C            MINIMUM VALUE
      C
      C
      C*************************************************************************
      C
0001          IMPLICIT REAL*8(A-H,O-Z)
0002         BYTE BUF2(80)
0003         BYTE BUF(80)
0004         REAL DAT(800),AHW(100)
0005            NUM=0
0006           XMIN=1000.
0007           XMAX=0.
0008           SAMSEC=2.56*2000
0009           F1=SAMSEC/(1024*2)
      C*****     READ DATA ARRAY FROM FILES.
      C*****   THE FILE LIST CONTAINS A LIST OF FILE NAMES TO BE AVERAGED.
      C
0010         WRITE(5,220)
0011  220    FORMAT(' ENTER NAME OF FILE LIST  ',$)
0012         READ(5,300) (BUF(I),I=1,80)
0013  300    FORMAT(80A1)
0014         L=LENGTH(BUF,80)
0015         BUF(L+1)=0
      C
      C*****     ASSIGN LOGIC UNIT 2 TO FILE LIST.
      C
0016         CALL ASSIGN(2,BUF)
      C
      C      ENTER NUMBER OF FILES IN FILE LIST.
      C
0017         WRITE(5,230)
0018  230    FORMAT(' ENTER NUMBER OF FILES  ',$)
0019         READ(5,240) NUM
0020  240    FORMAT(I5)
      C
0021           FN=FLOAT(NUM)
0022           TOT=0.
0023           TOT2=0.
0024         DO 133 J=1,NUM
0025            READ(2,300) (BUF2(I),I=1,80)
0026            L=LENGTH(BUF2,80)
0027            BUF2(L+1)=0
      C
      C
```

```
      C*****      OPEN FILE(I) AS LOGIC UNIT ONE.
      C
0028              CALL ASSIGN(1,BUF2)
      C
      C*****      READ FROM FILE(I).
      C
0029              READ(1,203) (DAT(I),I=1,800)
0030              CALL CLOSE(1)
      C
0031             TOTAL=0.
0032             DO 5 K=1,800
0033             FR=FLOAT(K)*F1
0034             IF(FR.LT.5.) GO TO 5
0036             IF(FR.GT.1500) GO TO 53
0038             IF(FR.LT.16.) GO TO 51
0040             CK=16./FR
0041             GO TO 52
0042  51         CK=1.
0043  52         CONTINUE
0044             DAT(K)=(DAT(K)*CK)**2
0045             TOTAL=TOTAL+DAT(K)
0046  5          CONTINUE
0047  53         CONTINUE
0048             AHW(J)=SQRT(TOTAL)*9.81
0049             IF(AHW(J).GT.XMAX) XMAX=AHW(J)
0051             IF(AHW(J).LT.XMIN) XMIN=AHW(J)
0053             TOT=TOT+AHW(J)
0054             TOT2=TOT2+AHW(J)**2
0055  133        CONTINUE
0056             XMEAN=TOT/FN
0057             IF(NUM.EQ.1) SD=0.
0059             IF(NUM.EQ.1)GO TO 535
0061             SD=SQRT(FN*TOT2-TOT**2)/(FN*(FN-1))
0062  535        CONTINUE
      C          WRITE RESULTS INTO FILES
0063             CALL ASSIGN(1,'AHW.DAT')
0064             WRITE(1,203)(AHW(J),J=1,NUM)
0065             WRITE(1,204)XMEAN,SD,XMAX,XMIN
0066  203        FORMAT(6E13.5)
0067  204        FORMAT(1X,'MEAN=',E13.5,'SD=',E13.5,'MAX=',E13.5
          *      ,'MIN=',E13.5)
0068             STOP
0069             END
```

FORTRAN IV STORAGE MAP FOR PROGRAM UNIT .MAIN.

LOCAL VARIABLES, .PSECT $DATA, SIZE = 007476 (1951. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
CK	R*8	007416	FN	R*8	007342	FR	R*8	007406
F1	R*8	007326	I	I*2	007336	J	I*2	007372
K	I*2	007404	L	I*2	007340	NUM	I*2	007274
SAMSEC	R*8	007316	SD	R*8	007436	TOT	R*8	007352
TOTAL	R*8	007374	TOT2	R*8	007362	XMAX	R*8	007306
XMEAN	R*8	007426	XMIN	R*8	007276			

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
AHW	R*4	$DATA	006440	000620 (200.)	(100)
BUF	L*1	$DATA	000120	000120 (40.)	(80)
BUF2	L*1	$DATA	000000	000120 (40.)	(80)
DAT	R*4	$DATA	000240	006200 (1600.)	(800)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ASSIGN	R*8	CLOSE	R*8	FLOAT	R*8	LENGTH	I*2	SQRT	R*4

```
      C
0001          INTEGER FUNCTION LENGTH (BUF,N)
      C
      C       THIS FUNCTION FINDS THE LENGTH OF A LINE
      C
0002          BYTE BUF(1),BL
0003          INTEGER N
0004          DATA BL/32/
      C
      C       LOOP TO FIND LAST LETTER
      C
0005          DO 100 I=N,1,-1
0006          IF (BUF(I) .NE. BL ) GO TO 200
0008    100   CONTINUE
0009    200   LENGTH =I
0010          RETURN
0011          END
```

```
FORTRAN IV STORAGE MAP FOR PROGRAM UNIT LENGTH

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000014 (     6. WORDS)

NAME   TYPE  OFFSET     NAME   TYPE  OFFSET     NAME   TYPE  OFFSET
BL     L*1   000006     I      I*2   000012     LENGTH I*2   000004 Eqv
N      I*2 @ 000002

LOCAL AND COMMON ARRAYS:

NAME     TYPE    SECTION OFFSET  ------SIZE----- DIMENSIONS
BUF    L*1     @ $DATA   000000  000001 (     1.) (1)

>
```

VWFTOCT,VWFTOCT=VWFTOCT

```
      C***    PROGRAM VWFTOCT
      C***    PROGRAM TO COMPUTE THIRD OCTAVE ANALYSIS OF VIBR
      C***    ATION RECORD ACCORDING TO ISO DIS 534 (JAN 83)
      C***    PROGRAM (1)COMPUTES THIRD OCTAVE ANALYSIS OF RMS
      C***               SPECTRUM DATA (5-1500HZ) OBTAINED FROM
      C***               NICOLET USING PROGRAM NIC AND STORES
      C***               DATA IN TOCT.DAT AND CORRESPONDING
      C***               FREQUENCY LIMITS IN FRX.DAT
      C***               FOR DUAL 1K MODE N=1024
      C***               FOR CHA 2K  MODE N=2048
      C***               SAMSEC=SAMPLING RATE=2.56*MAX FREQ
      C***          (2)COMPUTES WEIGHTED ACCELERATION LEVEL
0001          IMPLICIT REAL*8(A-H,O-Z)
0002          BYTE BUF(80)
0003          REAL Y(2048),X(300),TOCT(300)
0004          N=1024
0005          NN=N-1
0006          SAMSEC=2.56*2000
0007          WRITE(5,951)
0008  951     FORMAT('  ENTER NAME OF FILE TO BE ANALYSED     ',$)
      C***    PROGRAM ASSUMES THAT THIS FILE IS IN  G'S
0009          READ(5,950)(BUF(I),I=1,80)
0010  950     FORMAT(80A1)
0011          L=LENGTH(BUF,80)
0012          BUF(L+1)=0
0013          CALL ASSIGN(1,BUF)
0014          WRITE(5,1001)N,SAMSEC
      C***    READ RMS DATA AND SQUARE TO GET POWER SPECTRUM
      C***    FIRST LINE OF DATA FILE FROM 'NIC' IS SCALE FACT
      C***    OR WHICH MUST BE DELETED BEFORE USING FILE
0015          READ (1,902) (Y(I),I=1,NN)
0016          REWIND 1
      C***    CONVERT TO POWER SPECTRUM IN M/S**2
0017          DO 10 I=1,NN
0018          Y(I)=(Y(I)*9.8)**2
0019  10      CONTINUE
0020          Y(1024)=0.
0021          CALL TOCTV(N,Y,SAMSEC,X,TOCT)
      C***    N REDEFINED BY TOCTV
0022          CALL ASSIGN (3,'FRX.DAT')
0023          CALL ASSIGN (2,'TOCT.DAT')
0024          WRITE(5,904)N
0025          DO 500 I=1,N
0026          IF(X(I).LT.1.) GO TO 60
0028          XLG=ALOG10(X(I))
0029          GO TO 61
0030  60      XLG=0.
0031  61      IF(TOCT(I).LT.0.1) GO TO 62
0033          TOCTLG=ALOG10(TOCT(I))
0034          GO TO 63
0035  62      TOCTLG=-1.
0036  63      CONTINUE
0037  500     CONTINUE
0038          WRITE(2,902)(TOCT(I),I=1,N)
```

```
0039            WRITE(3,902)(X(I),I=1,N)
      C***      TOCT(I) IS IN M/S**2
      C***      CALCULATE WEIGHTED ACCELERATION OF NICOLET DATA
      C***      ACCORDING TO ISO DIS 5349(JAN 83)
0040            F1=SAMSEC/(1024*2)
0041            READ(1,902)(Y(I),I=1,NN)
0042            REWIND 1
0043            CALL CLOSE(1)
0044            TOTAL=0.
0045            DO 5 I=1,NN
0046            FR=FLOAT(I)*F1
0047            IF (FR.LT.5.) GO TO 5
0049            IF (FR.GT.1500.) GO TO 53
0051            IF(FR.LT.16) GO TO 51
0053            CK=16./FR
0054            GO TO 52
0055  51        CK=1.
0056  52        CONTINUE
0057            Y(I)=(Y(I)*CK*9.8)**2
0058            TOTAL=TOTAL+Y(I)
0059  5         CONTINUE
0060  53        CONTINUE
0061            AHW=SQRT(TOTAL)
0062            WRITE(5,1002)AHW
0063  1002      FORMAT(10X,'WEIGHTED ACCELERATION(M/S**2)FROM
          1     NICOLET=',F10.4)
      C***      CALCULATE WEIGHTED ACCELERATION OF THIRD OCTAVE
      C***      DATA ACCORDING TO ISO DIS 5349(JAN 83)
0064            TOTAL=0.
0065            DO 600 I=1,N
0066            J=2*I-1
      C***      CONVERT X(J) TO CENTRE FREQUENCY
0067            X(J)=X(J)*1.122462
0068            IF (X(J).LT.6.3) GO TO 600
0070            IF (X(J).GT.1260.) GO TO 630
0072            IF(X(J).LE.15.99) GO TO 610
0074            CK=16./X(J)
0075            GO TO 620
0076  610        CK=1.
0077  620        CONTINUE
0078            TOCT(I)=(TOCT(J)*CK)**2
0079            TOTAL=TOTAL+TOCT(I)
0080  600       CONTINUE
0081  630        CONTINUE
0082            NT=I
0083            AHW=SQRT(TOTAL)
0084            WRITE(5,1003)AHW
0085  1003      FORMAT(10X,'WEIGHTED THIRD OCTAVE ACCELERATION
          1     (M/S**2)=',F10.4)
0086  901       FORMAT(1X,I6,F14.6)
0087  902       FORMAT(6E13.5)
0088  903       FORMAT(1X, E16.8)
0089  904       FORMAT(10X,'NO OF POINTS IN TOCT ARRAY=',I6)
0090  1001      FORMAT(10X,'N=',I6,'SAMSEC=',F14.6)
```

```
      C***    CALCULATE RELATIVE CONTRINBUTION OF EACH BAND
0091          DO 640 J=1,NT
0092          TOCT(J)=TOCT(J)/TOTAL
0093  640     CONTINUE
0094          CALL ASSIGN(1,'RTOC.DAT')
0095          WRITE(1,902)(TOCT(J),J=1,NT)
0096          WRITE(1,905)NT
0097  905     FORMAT(1X,I5)
0098          REWIND 1
0099          STOP
0100          END
```

```
0001          SUBROUTINE TOCTV(N,PSPECT,SAMSEC,X,TOCT)
      C
      C       ROUTINE THIRD OCTAVE TAKES THE ARRAY CALLED PSPECT
      C       AND SUMS UP THE 'POWER' OR 'ENERGY' CONTAINED IN
      C       EACH OF THE THIRD OCTAVES. THE MIDDLE FREQUENCY OF
      C       THE THIRD OCTAVES START AT 1.0 HERTZ AND RUNS UP TO
      C       2 KILOHERTZ OR ONE-HALF THE SAMPLING RATE, WHICHEVER
      C       IS LEAST.
      C
      C       PARAMETERS WHICH ARE PASSED:
      C           N - THE NUMBER OF POINTS IN THE PSPECT ARRAY,
      C                   PASSED FROM THE MAIN PROGRAM
      C                   N IS ALSO THE NUMBER OF POINTS IN THE
      C                   X AND TOCT ARRAYS WHICH ARE DIFFERENT
      C                   IN LENGTH FROM THE PSPECT ARRAY, PASSED
      C                   BACK TO MAIN PROGRAM
      C           PSPECT - THE POWER SPECTRUM ARRAY, PASSED FROM
      C                   MAIN PROGRAM
      C           SAMSEC - THE SAMPLING RATE, PASSED FROM MAIN
      C                   PROGRAM
      C           X - THE ARRAY WHICH CONTAINS THE VALUES OF THE
      C                   UPPER AND LOWER BOUNDS OF THE THIRD
      C                   OCTAVES, PASSED BACK TO MAIN PROGRAM
      C           TOCT - THE ARRAY CONTAINING THE VALUES FOR THE
      C                   RMS ACCELERATION IN EACH OF THE THIRD OCTAVES,
      C                   PASSED BACK TO MAIN PROGRAM
      C
      C       PARAMETERS USED IN SUBROUTINE:
      C           F1 - THE FUNDAMENTAL FREQUENCY OF THE SIGNAL, THAT IS
      C                   THE LOWEST FREQUENCY THAT CAN BE DETERMINED
      C                   THE PERIOD OF THE FUNDAMENTAL FREQUENCY IS
      C                   THE TIME LENGTH OF THE SIGNAL. (THAT IS THE
      C                   PERIOD IS N TIMES THE TIME BETWEEN SAMPLES
      C                   OR N DIVIDED BY THE SAMPLING RATE)
      C           FC - THE CUTOFF FREQUENCY IS EQUAL TO ONE-HALF THE
      C                   SAMPLING RATE OR 2 KILOHERTZ, WHICHEVER IS
      C                   LEAST
      C           F - THE ARRAY WHICH KEEPS TRACK OF WHERE EACH
      C                   POWER SPECTRUM PEAK IS LOCATED. EACH OF
      C                   THE F ELEMENTS ARE A MULTIPLE OF F1.
      C
0002          INTEGER NUMF,KOUNT
0003          REAL PSPECT(1),X(300),TOCT(300),F(800),
             *    F1,FC,SAMSEC
      C
      C       CALCULATE FUNDAMENTAL FREQUENCY F1
      C
      C*      AS NICOLET USED 2048 SAMPLES F1=F1/2
0004          F1=SAMSEC/FLOAT(N)
0005            F1=F1/2
      C
      C       CALCULATE UPPER CUTOFF FREQUENCY FC
      C       NOTE: MAX FC = 2 KILOHERTZ
      C
```

FORTRAN IV STORAGE MAP FOR PROGRAM UNIT .MAIN.

LOCAL VARIABLES, .PSECT $DATA, SIZE = 025032 (5389. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
AHW	R*8	025010	CK	R*8	025000	FR	R*8	024770
F1	R*8	024750	I	I*2	024724	J	I*2	025020
L	I*2	024726	N	I*2	024710	NN	I*2	024712
NT	I*2	025022	SAMSEC	R*8	024714	TOCTLG	R*8	024740
TOTAL	R*8	024760	XLG	R*8	024730			

LOCAL AND COMMON ARRAYS:

NAME	TYPE	SECTION	OFFSET	------SIZE-----	DIMENSIONS
BUF	L*1	$DATA	000000	000120 (40.)	(80)
TOCT	R*4	$DATA	022400	002260 (600.)	(300)
X	R*4	$DATA	020120	002260 (600.)	(300)
Y	R*4	$DATA	000120	020000 (4096.)	(2048)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
ALOG10	R*4	ASSIGN	R*8	CLOSE	R*8	FLOAT	R*8	LENGTH	I*2
SQRT	R*4	TOCTV	R*8						

```
0006          FC=0.5*SAMSEC
0007          IF(FC.GT.2000.0) FC=2000.0
0009          N2=N/2
0010          KOUNT=1
      C
      C       CALCULATE UPPER AND LOWER CUTOFF FREQUENCIES FOR THIRD
      C       OCTAVES
      C
0011          X(1)=0.0
0012          X(2)=0.8908987184
0013          X(3)=0.8908987184
0014          DO 20 I=2,15
0015            X(2*I)=X(2*I-1)*1.259921050
0016            X(2*I+1)=X(2*I)
0017            IF(X(2*I).GT.FC) GOTO 1
0019            KOUNT=KOUNT+1
0020   20     CONTINUE
0021          DO 22 I=16,21
0022            X(2*I)=X(2*I-1)*1.254950721
0023            X(2*I+1)=X(2*I)
0024            IF(X(2*I).GT.FC) GOTO 1
0026            KOUNT=KOUNT+1
0027   22     CONTINUE
0028          DO 21 I=22,9999
0029            X(2*I)=X(2*I-1)*1.259921050
0030            X(2*I+1)=X(2*I)
0031            IF(X(2*I).GT.FC) GOTO 1
0033            KOUNT=KOUNT+1
0034   21     CONTINUE
      C
      C       CALCULATE THE VALUES OF THE F ARRAY
      C       NOTE: MAX F VALUE IS LESS THAN OR EQUAL TO FC
      C
0035    1     F(1)=F1
0036          DO 25 I=2,9999
0037            F(I)=F(I-1)+F1
0038            IF(F(I).GE.FC) GOTO 2
0040   25     CONTINUE
      C
      C       NUMF IS THE NUMBER OF ELEMENTS IN F ARRAY
      C
0041    2     NUMF=I
      C
      C       CALCULATE THE "ENERGY" IN EACH OF THE THIRD OCTAVES
      C
0042          TOCT(1)=0.0
0043          TOCT(2)=0.0
0044          K=1
0045          DO 30 I=2,KOUNT
0046            AREA=0.0
0047            DO 40 J=K,999
0048              IF(X(2*I-1).LE.F(J)) GOTO 3
0050   40       CONTINUE
0051    3       M=J
```

```
0052            DO 50 K=M,NUMF
0053              IF(F(K).GE.X(2*I)) GOTO 4
0055              AREA=AREA+PSPECT(K)
0056    50        CONTINUE
                  C
                  C     NOTE: THE "ENERGY" IN A THIRD OCTAVE IS THE SQUARE ROOT
                  C     OF THE SUM OF THE POWER SPECTRUM PEAKS IN THAT THIRD
                  C     OCTAVE
                  C
0057     4          AREA=SQRT(AREA)
0058                TOCT(2*I-1)=AREA
0059                TOCT(2*I)=AREA
0060    30        CONTINUE
                  C
                  C     THE VALUE OF N IS CHANGED, N IS NOW THE LENGTH OF THE
                  C     X AND TOCT ARRAYS
                  C
0061              N=2*KOUNT+1
                  C
                  C     THE LAST TOCT ELEMENT IS SET TO ZERO
                  C
0062              TOCT(N)=0.0
0063              RETURN
0064              END
```

FORTRAN IV STORAGE MAP FOR PROGRAM UNIT TOCTV

LOCAL VARIABLES, .PSECT $DATA, SIZE = 006274 (1630. WORDS)

NAME	TYPE	OFFSET	NAME	TYPE	OFFSET	NAME	TYPE	OFFSET
AREA	R*4	006246	FC	R*4	006234	F1	R*4	006230
I	I*2	006242	J	I*2	006252	K	I*2	006244
KOUNT	I*2	006226	M	I*2	006254	N	I*2 @	000000
NUMF	I*2	006224	N2	I*2	006240	SAMSEC	R*4 @	000004

LOCAL AND COMMON ARRAYS:

NAME	TYPE		SECTION	OFFSET	------SIZE-----	DIMENSIONS
F	R*4		$DATA	000012	006200 (1600.)	(800)
PSPECT	R*4	@	$DATA	000002	000004 (2.)	(1)
TOCT	R*4	@	$DATA	000010	002260 (600.)	(300)
X	R*4	@	$DATA	000006	002260 (600.)	(300)

SUBROUTINES, FUNCTIONS, STATEMENT AND PROCESSOR-DEFINED FUNCTIONS:

NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE	NAME	TYPE
FLOAT	R*4	SQRT	R*4						

VWFTOCT,VWFTOCT=VWFTOCT

```
0001            INTEGER FUNCTION LENGTH (BUF,N)
0002            BYTE BUF(1),BL
0003            INTEGER N
0004            DATA BL/32/
0005            DO 100 I=N,1,-1
0006            IF (BUF(I).NE.BL) GO TO 200
0008  100       CONTINUE
0009  200       LENGTH=I
0010            RETURN
0011            END
```

```
FORTRAN IV STORAGE MAP FOR PROGRAM UNIT LENGTH

LOCAL VARIABLES, .PSECT $DATA, SIZE = 000014 (     6. WORDS)

NAME   TYPE  OFFSET      NAME   TYPE  OFFSET      NAME   TYPE  OFFSET
BL     L*1   000006      I      I*2   000012      LENGTH I*2   000004 Eqv
N      I*2 @ 000002

LOCAL AND COMMON ARRAYS:

NAME      TYPE    SECTION OFFSET  ------SIZE----- DIMENSIONS
BUF     L*1     @ $DATA   000000  000001 (    1.) (1)

>by
```

POOR

QUALITY

ORIGINAL